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THE DEMAND FOR TREASURY DEBT

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ABSTRACT

We show that the US Debt/GDP ratio is negatively correlated with the spread between corporate bond yields and Treasury bond yields. The result holds even when controlling for the default risk on corporate bonds. We argue that the corporate bond spread reflects a convenience yield that investors attribute to Treasury debt. Changes in the supply of Treasury debt trace out the demand for convenience by investors. We show that the aggregate demand curve for the convenience provided by Treasury debt is downward sloping and provide estimates of the elasticity of demand. We analyze disaggregated data from the Flow of Funds Accounts of the Federal Reserve and show that individual groups of Treasury holders also have downward sloping demand curves. Even groups with the most elastic demand curves have demand curves that are far from flat. The results have bearing for important questions in finance and macroeconomics. We discuss implications for the behavior of corporate bond spreads, interest rate swap spreads, the riskless interest rate, and the value of aggregate liquidity. We also discuss the implications of our results for the financing of the US deficit, Ricardian equivalence, and the effects of foreign central bank demand on Treasury yields.

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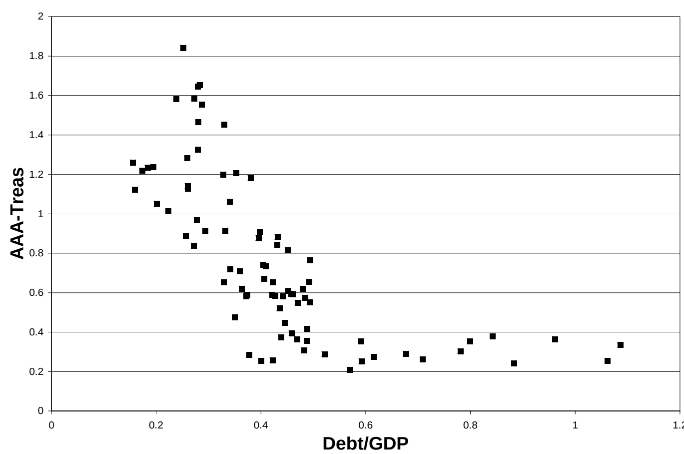
1 Introduction

Figure 1 graphs the yield spread between AAA rated corporate bonds and Treasury securities against the US government debt-to-GDP ratio (i.e. the ratio of the face value of publicly held US government debt to US GDP). The figure suggests that the corporate bond spread is high when the stock of debt is low, while the spread is low when the stock of debt is high.

Figure 1: Corporate Bond Spread and Government Debt



The corporate bond spread (y-axis) is graphed versus the $Debt/GDP$ ratio (x-axis) based on annual observations from 1925 to 2005. The bond spread is the difference between the percentage yield on Moody's AAA long maturity bond index and the percentage yield on long maturity Treasury bonds.

In the next sections of the paper, we argue that the negative correlation between the debt-to-GDP ratio and the corporate bond spread arises because of variation in the "convenience yield" on Treasury securities, rather than variation in the default risk of corporate borrowers. Investors place a value on Treasury securities – the convenience value – above and beyond the securities' cash flows. When the stock of debt is low, the marginal convenience valuation of debt is high. Investors bid up the price of Treasuries relative to other securities such as corporate bonds, causing the yield on Treasuries to fall further below corporate bond rates, and the bond spread to widen. The opposite applies when the stock of debt is high. Variation in the supply of Treasury securities traces out a downward sloping demand curve for Treasuries. We estimate the semi-elasticity of the corporate bond spread to the Debt/GDP ratio, finding that a hypothetical increase in the Debt/GDP ratio from the current level of 0.38 to a new level of 0.39 will raise long term Treasury yields by between 1.5*bps* (Table I-A, Panel B, column (2)) and 4.25*bps* (Table IV-B, column (2)), relative to corporate bond yields.

Sections 2, 3, 4, and 6 present these results relating the aggregate supply of Treasury securities to the spread between corporate and Treasury bond yields. We show that the results are robust to adding various controls for corporate default risk. We also show the results hold when the dependent variable is the spread between a short-maturity corporate bond and Treasury bond, or is the spread between the realized excess returns of corporate bonds over Treasury bonds. These results along with a number of other robustness checks presented in Section 8 strongly support the existence of a convenience yield on Treasury securities.

Section 5 of the paper examines which groups of investors are the strongest drivers of the convenience value of Treasury securities. We first argue that different groups of Treasury owners likely have different motives for holding Treasuries. We then estimate which groups have the least elastic demand curves in order to determine which of the various motives are likely to contribute substantially to the convenience yield on Treasuries. We offer three motives: The first is a *liquidity* motive. Treasury securities are extremely liquid in comparison to corporate bonds. For example, Reinhart and Sack (2000) note that bid-offer spreads on corporate bonds are four to six times larger than those of Treasury bonds. The liquidity motive is analogous to the demand for holding money. Like Treasuries, money offers a low rate of return and yet is held in equilibrium. Theories of money demand suggest that this is because agents derive special liquidity services from holding money. For official groups (foreign central banks, US regional Federal Reserve banks and US state and local governments) and for groups such as banks and households (including mutual funds) the liquidity of Treasuries may be very important. The second motive is a *neutrality* motive. Kohn (2005) suggest that a key reason for why the US federal reserve banks mainly hold Treasury securities is that they do not wish to favor any non-governmental borrower over another. A similar motive may apply to state and local governments and foreign central banks. The third motive is that Treasuries are widely considered the lowest risk interest bearing asset. The *surety* of Treasuries may be attractive for unsophisticated investors who are unable to assess the risk in corporate assets.

We study disaggregated data from the Flow of Funds Accounts and estimate demand curves for each of the main groups that hold Treasuries. We find that the Treasury demands of official groups (foreign central banks, US regional Federal Reserve banks and US state and local governments) are the least sensitive to the corporate bond spread. Banks, households and the foreign private sector have somewhat more elastic Treasury demands, while groups who likely have very long investment horizons (state/local government retirement funds, private pension funds and insurance companies) have the most elastic Treasury demands. These findings suggest the liquidity and neutrality motives are primary factors behind the "convenience value" from holding Treasuries.

Our results have bearing for important questions in both finance and macroeconomics. In section 7 of the paper we discuss implications of our findings for the behavior of corporate bond spreads, the riskless interest rate, the value of aggregate liquidity, and the financing of the US deficit. We also use our demand curve estimates to quantify the effects of foreign central bank demand on Treasury yields.

Relation to Literature

Our finding of a significant non-default component in the corporate bond spread is consistent with some recent papers in the corporate bond pricing literature (see Collin-Dufresne, Goldstein, and Martin (2001), Huang and Huang (2001), and Longstaff, Mithal, and Neis (2005)). We also present evidence that the interest rate swap spread – that is the spread between corporate-referenced swap rates and Treasury bond rates – has a significant non-default component. Duffie and Singleton (1997), Grinblatt (2001), He (2001), Liu, Longstaff, and Mandell (2004), Li (2004), and Feldhutter and Lando (2005) argue for a significant non-default component in the interest rate swap spread. Papers in the prior literature use information from the corporate bond market to estimate the default component of interest rate spreads, and label the residual as a non-default component.[1] Compared to the prior literature, the novelty of our work is to offer a direct test of the convenience yield hypothesis and to document that the amount of Treasuries outstanding is a key driver of the non-default component of the corporate bond spread and of the interest rate swap spread.

We are aware of only a few papers in the literature that have noted a correlation between the supply of government debt and interest rate spreads. Cortes (2003) documents a correlation between the US Debt/GDP ratio and swap spreads over a period from 1994 to 2003. Longstaff (2004) documents a correlation between the supply of Treasury debt and the spread between Refcorp bonds and Treasury bonds over a period from 1991 to 2001.[2,3] Relative to both Cortes and Longstaff we study a longer sample, provide a theoretical basis to study the relation, and present a more detailed empirical analysis. In particular, we use several approaches to rule out that the relation could be driven by time-varying default risk, and we estimate group

[1] Some of the papers in the prior literature also show that the non-default component is related to the specialness of particular Treasury securities. A particular Treasury bond is "special" if the cost of borrowing the bond in the repurchase market exceeds that of other Treasury bonds with similar maturity and cash-flow characteristics. Specialness leads to the yield on the special Treasury bond to fall below comparable Treasury bonds. See Krishnamurthy (2002) for further discussion of specialness. In a sense, we show that the entire Treasury market is "special" relative to other asset markets, and not just that one Treasury is special relative to another Treasury.

[2] Jovanovic and Rousseau (2001), Krishnamurthy (2002), and Sundaresan and Wang (2006) present evidence that the auctioned amount of specific Treasury securities affects the value of these securities. Krishnamurthy (2002) and Sundaresan and Wang (2006) suggest that the link is due to the specialness of particular Treasury securities. These papers offer evidence that supply has an effect on the relative price of Treasury securities to other Treasury securities, not the relative price of Treasury securities to non-Treasury assets.

[3] Reinhart and Sack (2000) document a relation between the projected government deficit and the slope of the Treasury yield curve. They suggest that the relation is evidence of a supply effect: An expected change in the stock of debt causes investors to change the yield on long-term Treasury securities more than that of short-term securities.

level demand curves to shed light on which motives drive the relation between the corporate bond spread and the supply of Treasuries at the aggregate level. Dittmar and Yuan (2006) study a sample of sovereign and corporate bonds in emerging markets and show that the issuance of new sovereign bonds lowers yield spreads and bid-ask spreads of existing corporate bonds. Their result is suggestive that the convenience yield in government bonds may be an international phenomenon.

In macroeconomics, there is a large literature exploring the Ricardian equivalence proposition (Barro, 1974), that the financing choices of the government used to fund a given stream of government expenditures is irrelevant for equilibrium quantities and prices. One implication of the Ricardian equivalence proposition is that the size of government debt has no causal effect on interest rates. Despite a large amount of research devoted to studying this topic, there is yet no clear consensus on the effects of debt on interest rates (see, for example, the survey by Elmendorf and Mankiw (1999)). Barro (1987), Evans (1986) and Plosser (1986) find little or no effect of government debt on interest rates. Laubach (2005) does find such an effect when using forecast levels of government debt rather than currently measured levels (Laubach reports a $4-5$ *bps* effect per one percentage point increase in Debt/GDP). We provide evidence that the stock of debt affects the interest rates on government bonds. But it is important to note that the effect we identify is on the spread between government interest rates and corporate interest rates. It is possible that Ricardian equivalence fails in a way that government debt has an effect on the general level of interest rates, both corporate and government. Since we focus on spreads, we are unable to isolate such an effect. On the other hand, as we focus on spreads, we can be certain that the effect we identify on government interest rates is over and above any possible effects of government debt on the general level of interest rates. From an empirical standpoint, the advantage of focusing on spreads rather than the level of interest rates is that the spread measure is unaffected by other shocks (such as changes in expected inflation) that affect the level of interest rates and complicate inference. We also bypass endogeneity issues stemming from government behavior, since it is unlikely that the government chooses debt levels based on the corporate bond spread.

At a broad level, our evidence is consistent with theories that ascribe a unique value to government debt. Bansal and Coleman (1996) present a theory in which debt, but not equity claims, are money-like and carry a convenience value. They argue that the theory can account for the high average equity premium and low average risk-free rate in the US.[4] Our finding of a unique value provided by government debt relative to private debt support theories such as Woodford (1990), Holmstrom and Tirole (1998), and Caballero and Krishnamurthy (2006). In these papers, the government's credibility gives its securities unique collateral and liquidity features relative to private assets and thereby induces a premium on government assets.

[4] Aiyagari and Gertler (1990), Heaton and Lucas (1996), and Vayanos and Vila (1999) present general equilibrium models in which an illiquid asset (i.e. stocks) carries a transaction cost while a liquid asset (bonds) do not. In equilibrium, the liquid asset has a liquidity premium over the illiquid asset. Eisfeldt (2006) studies whether the liquidity premium between short term bonds and longer term bonds can by rationalized in a calibrated consumption smoothing model, finding that it cannot.

2 The Convenience Yield on Treasury Securities

We articulate the convenience yield theory in the context of a representative agent asset-pricing model. We price securities at date t that mature at date $t+\tau$. The agent chooses holdings of these securities to maximize utility:

$$u(c_t) + \beta^\tau u(c_{t+\tau}).$$

The Euler equation for the agent pins down the prices of assets at date t. For a riskless Treasury bond that pays one unit of consumption at date $t+\tau$,

$$P_t^T = E\left[m_{t+\tau}\right], \quad m_{t+\tau} \equiv \beta^\tau \frac{u'(c_{t+\tau})}{u'(c_t)}.$$

$m_{t+\tau}$ is the τ-period pricing kernel in the economy. For a corporate bond with face value of one and repayment $1+D_{t+\tau}^C$ (where $D_{t+\tau}^C = 0$ in the absence of default and $D_{t+\tau}^C < 0$ if there is default on the bond) at date $t+\tau$,

$$P_t^C = E\left[m_{t+\tau}(1+D_{t+\tau}^C)\right].$$

We compute the spread between corporate and Treasury bond yields in this model as follows. First, we define,

$$y_t^T = -\frac{1}{\tau} lnP_t^T \quad \text{and,} \quad y_t^C = -\frac{1}{\tau} lnP_t^C$$

as the yields on the corporate and Treasury bonds. These formula convert the price of a zero coupon bond into a continuously compounded zero coupon bond yield. Then, the corporate bond yield spread is equal to

$$\begin{aligned} y_t^C - y_t^T &= \frac{1}{\tau}\left(ln\ E[m_{t+\tau}] - ln\ E[m_{t+\tau}(1+D_{t+\tau}^C)]\right) \\ &\approx \frac{1}{\tau}\left(E[m_{t+\tau}] - E[m_{t+\tau}(1+D_{t+\tau}^C)]\right) \\ &= \frac{1}{\tau}E[-D_{t+\tau}^C]E[m_{t+\tau}] + \frac{1}{\tau}cov(m_{t+\tau}, -D_{t+\tau}^C) \end{aligned}$$

The approximation going from the first to second line uses the relation that $ln(1+x) \approx x$ for small x. For high grade corporate and government debt on which interest rates are low, bond prices may be close to one. Although it is clear that the approximation is imperfect in some circumstances, we make the approximation to motivate our empirical specification.

We define,

$$\Delta_t^* = \overbrace{\frac{1}{\tau}E[-D_{t+\tau}^C]E[m_{t+\tau}]}^{\text{Default Risk}} + \overbrace{\frac{1}{\tau}cov(m_{t+\tau}, -D_{t+\tau}^C)}^{\text{Risk Premium}} \tag{1}$$

as the "C-CAPM" value of the spread between corporate bonds and Treasury bonds. The spread has two components.[5]

[5] There is a third component in the spread of equation (1) that arises if we consider the differential tax treatment of corporate and Treasury bonds. We discuss the tax component in Section 8.2.

The first term on the right-hand side reflects the expected losses due to default on corporate bonds ("default risk"). Higher expected defaults leads to a higher yield spread. The second term on the right hand side reflects the economic "risk premium" attached to default states. Depending on how default covaries with the marginal utility of the representative agent, default may carry an additional risk premium.

We next modify this model to introduce a convenience value of Treasury securities. We observe that Treasury securities offer unique services to agents in the economy. As noted in the introduction, some agents are motivated to buy Treasuries for liquidity reasons, some for neutrality reasons, and others for the surety that Treasuries offer. These motives will be reflected in the aggregate demand for Treasury securities. We use the word "convenience" value to encompass the many motives for holding Treasuries. Section 5 of the paper offers microeconomic evidence on the different sources of convenience demand.

The convenience demand theory is analogous to theories of money demand. Agents hold money despite the fact that it is a dominated asset because it offers unique liquidity services. At any point in time, the convenience yield on money can be inferred from the overnight federal funds rate, since that is the price at which an agent can obtain the services of money for one day. Similarly, we argue that the convenience yield on Treasury securities can be inferred from asset prices.

We modify the representative agent utility function to include a term whereby the agent receives utility from his Treasury holdings:

$$u(c_t) + \beta^{\tau} u(c_{t+\tau}) + v(\theta_t^T; X_t).$$

$v(\cdot)$ reflects the unique services provided by Treasury securities, with $v'(\cdot) > 0$ and $v''(\cdot) < 0$. θ_t^T is the agent's holdings of Treasury debt and X_t are some of the factors that might affect the valuation. This modification is similar to monetary models with money in the utility function.

For this modified model,

$$P_t^T = E\left[m_{t+\tau}\right] + \frac{v'(\theta_t^T; X_t)}{u'(c_t)}$$

We repeat the steps of converting prices into yields and find,

$$y_t^C - y_t^T \quad \approx \quad \overbrace{\frac{1}{\tau}E[-D_{t+\tau}^C]E[m_{t+\tau}]}^{\text{Default Risk}} \; + \; \overbrace{\frac{1}{\tau}cov(m_{t+\tau}, -D_{t+\tau}^C)}^{\text{Risk Premium}} \; + \; \overbrace{\frac{v'(\theta_t^T; X_t)}{\tau u'(c_t)}}^{\text{Convenience Yield}} \qquad (2)$$

As in equation (1), the yield spread has a default risk component and a risk premium component. Since Treasury securities are also assumed to provide a convenience value, the bond spread is increased by a convenience yield.

Note that if $v'(\cdot)$ is equal to zero the yield spread corresponds exactly to our previous C-CAPM yield spread. The introduction of convenience valuation widens the yield spread (last term).

For simplicity we rewrite the convenience yield term as follows. Since the factors (X_t) that affect the convenience valuation, $v'(\cdot)$, may include time t variables such as $u'(c_t)$, for brevity, we do not divide $v'(\cdot)$

by $\tau u'(c_t)$ and simply write,[6]

$$y_t^C - y_t^T = \Delta_t^* + v'(\theta_t^T; X_t)$$

The yield spread characterizes the agent's demand function for Treasury debt. If the US government supplies Θ_t^T of debt, then the equilibrium spread we should observe in the market is:

$$\Delta_t^* + v'(\Theta_t^T; X_t) \tag{3}$$

We refer to Δ_t^* as the "default" component of the corporate bond spread, and $v'(\cdot)$ as the "non-default" component of the corporate bond spread. Recall from (1) that the default component includes both a default risk component as well as a risk premium component.

Figure 2 represents the equilibrium spread determination graphically. The marginal valuation of Treasury securities is reflected in the downward sloping function $D(\theta_t^T; X_t) = \Delta_t^* + v'(\theta_t^T; X_t)$. This valuation is always at least Δ_t^*, the C-CAPM value of the spread. At the margin, the valuation decreases as the agent holds more Treasury debt. The supply of Treasury debt is represented by the vertical line at Θ_t^T. In the convenience yield model the spread falls as Θ_t^T rises.

3 Estimation

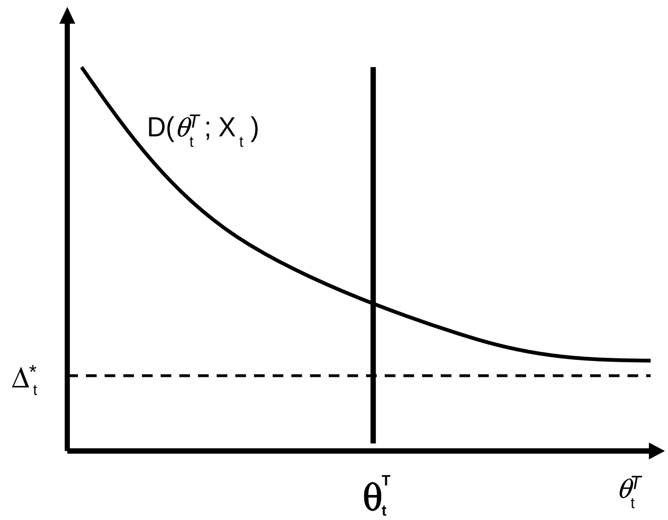
Our baseline regressions involve the time series of the bond yield spread (the yield on corporate bonds minus the yield on Treasuries) as the dependent variable and the log of ratio of the stock of US government debt to US GDP as the independent variable, along with a number of controls we discuss below. Our convenience yield theory implies that the coefficient on (log) government Debt/GDP in this regression will be negative.

The main difficulty with interpreting such a regression is that changes in Θ_t^T/GDP_t may be correlated with changes in Δ_t^*, so that the regression of the bond spread on $log(\Theta_t^T/GDP_t)$ may yield a significant coefficient, despite there being no causal relation running from Θ_t^T/GDP_t to the spread. For example, suppose that the true model is the C-CAPM, but increases in Θ_t^T/GDP_t are correlated with decreases in Δ_t^*. Then, we will find a negative coefficient on $log(\Theta_t^T/GDP_t)$ despite there being no convenience yield on Treasuries.

There are two principal sources of such a correlation. Our primary concern is an omitted variable bias. If there is an economic shock that causes the government to increase Θ_t^T and that also causes corporate default risk to fall or the default risk premium charged by investors to fall, and our regressions do not control for

[6]To motivate this simplification, note that if c_t/GDP_t is constant across time, then $u'(c_t)$ can be written as a function of GDP_t. In our regressions we include GDP_t as one of the X_t regressors. In the data the ratio c_t/GDP_t is relatively stable over time.

Figure 2: Bond Spread and Total Debt



The figure graphically illustrates the equilibrium determination of the spread between Treasury bond yields and corporate bond yields. The downward sloping curve is the demand for Treasury securities as a function of the spread in our convenience yield model. In the neoclassical C-CAPM model, this demand function is completely elastic at the representative agent's risk prices. The horizontal dashed line in the figure corresponds to the C-CAPM demand. The supply of Treasury securities is represented by the vertical line at Θ_t^T. We assume that the government does not choose the stock of debt in response to the bond spread; hence the supply curve is inelastic.

this shock, then our estimates will be biased.[7,8]

The solid line in Figure 3 plots the US Debt/GDP ratio from 1925 to 2005. The two main forces behind changes in the Debt/GDP ratio are wars and the business cycle (see Bohn (1998)). From the figure we see

[7]The spread, Δ_t^* could also fall if government debt becomes more risky when Θ_t^T rises, holding the risk of corporate debt fixed. This seems implausible on a priori grounds. The government can always print money to pay off its debt. While this possible action may lead to (expected) inflation and thereby raise the interest rate on government debt, it will lead to an equal rise in the interest rate on corporate debt and no effect on our spread measure.

[8]A related concern with our estimation has to do with interpreting the coefficient on $log(\Theta_t^T/GDP_t)$ as the slope of agents' demand curve. That is, suppose that consistent with our convenience yield theory, the true demand curve for Treasuries is downward sloping. If there is a correlation between shifts in demand (X_t) and shifts in supply (Θ_t^T) that is not adequately controlled for, the coefficient on Θ_t^T will be a biased estimate of the slope of agents' demand curve. We deal with this issue in the regressions by controlling for demand shocks and presenting instrumental variables regressions.

that the Debt/GDP ratio rises during the Great Depression starting in 1930 and going through the mid-1930s. The ratio rises again during the WWII period. The peacetime expansion beginning in 1950 gradually reduces the Debt/GDP ratio until about 1980 when the Reagan military build up expands the ratio again. Through the 1990s the ratio falls as the economy expands again. The ratio rises again starting in 2001, coincident with 9/11 and recessionary conditions. Thus, broadly speaking, war spending and recessions increase the Debt/GDP ratio, while expansions reduce the ratio.

We note that, a priori, a negative economic shock that causes the government to increase the debt stock is more likely to *increase* than decrease Δ_t^*, so that the omitted variable bias may be less of a problem for our regressions.

Empirically we deal with the omitted variable bias in three ways. First, we introduce controls that attempt to directly capture variation in Δ_t^*. We include corporate sector credit risk variables and business cycle measures that may control for changes in default risk and default risk premia. We also include standard controls for changes in marketwide risk premia such as the slope of the yield curve. Second, we present regressions where the dependent variable is the realized excess return on corporate bonds over government bonds (as opposed to the yield spread). Since return realizations encompass default-related events such as corporate bond downgrades, the return series will not be affected by the default risk term in (2). In these regressions, we also include proxies for marketwide risk premia to control for the risk premium in the corporate bond returns. Last, we study disaggregated data where we present evidence consistent with our theory based on instrumental variables regressions.

The second source of correlation in our setting arises because government behavior may both cause changes in the Debt/GDP ratio and the corporate bond spread. Suppose that a shock that we have not controlled for causes the government to spend resources (or lower taxes) in a way that increases the revenues of the corporate sector and raises the Debt/GDP ratio, then the default risk premium component Δ_t^* will fall when Θ_t^T rises. We deal with this concern as an omitted variable bias, and as explained above.

Finally, note that the usual reverse causality concern that government behavior is an endogenous response to a change in prices is less of a concern in our setting because the price variable is a corporate bond spread. The US government is unlikely to choose the stock of outstanding debt in response to a change in the default risk of corporate bonds relative to Treasuries. It seems plausible that the government's decision may respond to a change in the level of interest rates, but not a change in default spreads. Indeed, this is why we represent the supply curve in Figure 2 as a vertical line. Our use of interest rate spreads rather than the level of interest rates to discern the effects of government debt policy avoids a number of difficult issues that prior work testing Ricardian equivalence has had to contend with.

4 Aggregate Demand for Treasury Debt

We adopt the following functional form in the regressions. We assume that $v'(\cdot)$ can be written as:

$$v'(\Theta_t^T; X_t) = A + B\ log\ (\Theta_t^T/GDP_t), \quad \text{where} \quad B < 0.$$

The demand for Treasury debt should increase as the economy becomes larger. That is, as the economy grows, there is greater demand for Treasury securities for liquidity purposes, there are more official transactions involving Treasury securities, and there are more unsophisticated households seeking savings vehicles. We scale the stock of Treasuries by US GDP to measure this demand effect.

The log function reflects that the marginal convenience valuation decreases more slowly as Θ_t^T increases, consistent with Figure 2. In contrast to our convenience yield theory, the log specification implies that v' may become negative. However, this only happens in two of the years we analyze (1945 and 1946 when the US Debt/GDP ratio is above one).[9] We adopt the log function primarily so that the coefficient, B, can be interpreted as the semi-elasticity of the bond spread with respect to the stock of debt. We present regressions based on an exponential specification where v' is always positive in Section 5. Over the range of variation of the Debt/GDP ratio, the results from the exponential specifications are almost identical to the log specification.

The linear regressions we present are thus for the relation:

$$S_t = A + B\ log\ (\Theta_t^T/GDP_t) + C\ Y_t + \epsilon_t \tag{4}$$

using S_t as a time series of bond yield spreads, Θ_t^T as the book value of publicly held Treasury debt, with controls for other factors (Y_t) that affect the C-CAPM value of the spread. We are centrally interested in estimating the semi-elasticity B.

Note that we use the book value of Treasury debt rather than market value because our equilibrium relation, (3), expresses prices (the spread) as a function of quantities (book value of Treasury debt). If we were to use the market value of Treasury debt, the quantity measure would also reflect market prices.

4.1 Corporate Bond Spread

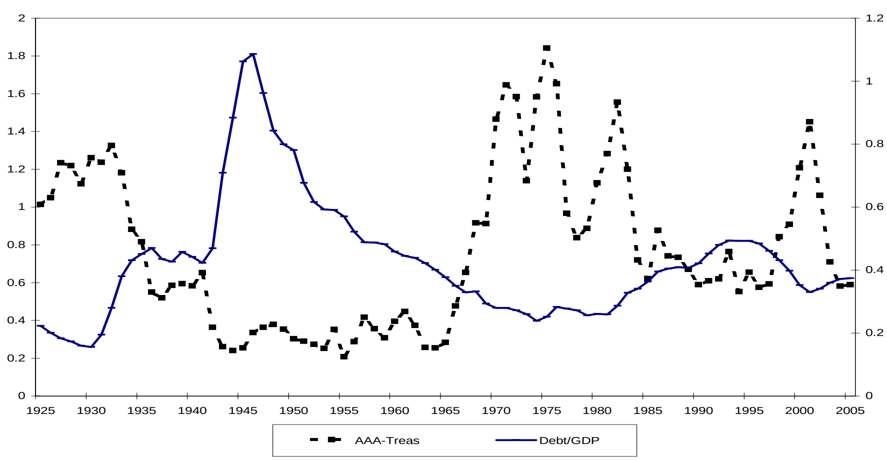
Figure 3 graphs the percentage spread between the Moody's AAA long maturity bond yield and the average yield on long maturity (> 10 years) Treasury bonds. Both data series are from the Federal Reserve's FRED database and extend from 1925 to 2005 in the figure. The Moody's index is constructed from a sample of long maturity (> 10 years) industrial and utility bonds. The Treasury yield is available from 1925 - 1999,

[9] Omitting these years leads to slightly stronger results, i.e. a steeper relation between the bond yield spread and the Debt/GDP ratio. See Section 8.

while the Moody's AAA yield is available from 1919 - 2005.[10] We use the yield on 20 year maturity Treasury bonds for 2000 - 2005.[11]

The figure also graphs the Debt/GDP ratio in the US over the same period. The Debt/GDP ratio for years up to 2003 are downloaded from Henning Bohn's website. The data series is updated until 2005 from the Office of Management and Budget. Bohn constructs the measure as the ratio of privately held Treasury debt (from the WEFA database, Federal Reserve Banking and Monetary Statistics, and recent issues of the Economic Report to the President) relative to either GDP (after 1959) or GNP (prior to 1959). Privately held debt includes debt held by the Federal Reserve, but excludes debt held by other parts of the government such as the Social Security Trust Fund. In Section 8 we present results where we construct privately held debt by also excluding the Federal Reserve's debt holdings. The robustness check is for the period after 1945 when we can break out the Federal Reserve holdings.

Figure 3: Corporate Bond Spread and Government Debt



The corporate bond yield spread (left y-axis) and $Debt/GDP$ ratio (right y-axis) are graphed from 1925 to 2005. The corporate bond yield spread is the percentage difference between the yield on Moody's AAA bond index and the yield on long maturity Treasury bonds.

[10]The corporate bond and Treasury bond yields are for coupon bonds, not zero-coupon bonds, as derived in our simplified theory.

[11]While both the Moody's AAA yield and Treasury yield correspond to bonds with approximately 20 year maturities, there may be mismatch in the exact maturities between the bonds. We add a covariate measuring the slope of the yield curve to control for the maturity mismatch effect.

Figures 1 and 3 suggest that there is a negative correlation between the bond yield spread and the stock of Treasury debt. Table I presents regressions relating the yield spread between AAA rated corporate bonds and Treasury securities, and the log US Debt/GDP ratio. Column (1) of the table confirms the statistical significance of the relation suggested by Figures 1 and 3. The coefficient of -0.77 implies that a one standard deviation (0.42) increase in log(Debt/GDP) reduces the bond yield spread by 32 basis points.

As noted above, the default risk on corporate bonds varies with the state of the economy. This variation also affects the corporate bond spread (Δ_t^* in the theoretical framework). We control for default risk using the spread between the Moody's BAA minus Moody's AAA long maturity bond yields, which measures the relative default risk of lower and higher grade corporate bonds. We rationalize using this spread to measure default risk by noting that if default risk of the corporate sector rises, or the risk premium investors demand for absorbing default risk rises, one would expect to see an increase in the yield spread between higher and lower grade corporate bonds. Thus the BAA-AAA spread will capture time variation in corporate default risk as well as time variation in the market price of default risk (equation (1)). The Moody's BAA series is from the Federal Reserve's FRED database.

As expected, the default risk variable is significant and positively related to the corporate bond spread (column (2)). However, adding the control does not alter the importance of $log(Debt/GDP)$ much. Table XI of Section 8 reports regressions that include some other measures of corporate default risk.

We include the slope of the yield curve, measured as the spread between the 10 year Treasury yield and the 3 month Treasury yield (*slope*), to further control for the economic risk premium component of Δ_t^*. The interest rate on Treasuries with three month maturity is from FRED from 1934 to 2005 and from the NBER macro data base prior to that. The interest rate on Treasuries with ten year maturity is from FRED from 1953 to 2005 and from the NBER macro data base prior to that.

The slope of the yield curve can measure the state of the business cycle and is known to predict the excess returns on stocks. For example, if investors are more risk averse in a recession, when the slope is high, they will demand a higher risk premium to hold corporate bonds. Thus, slope serves as a second measure of variation in Δ_t^*. We also note that to the extent that corporate default risk is likely to vary with the business cycle, the slope variable can also control for the default risk component of Δ_t^*. The regression is reported in column (3) of the Table and results in similar coefficient estimates on the $log(Debt/GDP)$ variable. We have also run specifications that include the price/earnings ratio on the stock market to measure investor risk aversion. The inclusion of this control does not alter our findings. The results are available upon request.

The results reported in Panel A of the table are OLS time series regressions. Because the underlying series are persistent, the regression residuals are autocorrelated. All of the regressions report t-statistics based on Newey-West robust standard errors that allow for first order autocorrelation. Panel B presents our final specifications, where we assume that the regressions residuals are AR(1) and use a GLS approach to obtain more efficient estimates. Specifically, the regressions are Cochrane-Orcutt AR(1) iterated regressions. They confirm the findings in Panel A.

Table I-B presents similar regressions to those reported in Table I-A, but using a one year corporate to Treasury spread as dependent variable, rather than the approximately 20 year spread of Table I-A. The dependent variable is constructed using commercial paper (CP) and Treasury bills data.[12]

The results reported are in line with those of Table I-A. Increases in $log(Debt/GDP)$ decrease the CP-Bill yield spread. This result holds across all of our specifications.[13]

The coefficient estimates of the semi-elasticity and the regression R^2s are smaller for the CP-Bill yield spread regressions than the long term corporate bond yield spread regressions. We think this occurs because CP is more liquid relative to T-bills than AAA corporate bonds are relative to Treasury bonds. The lower R^2s may also be due to the CP-Bill spread moving at a higher frequency than the Debt/GDP ratios. Changes in the riskiness of corporate cash-flows may have larger effects on a short-term credit spread than a long term credit spread. Note that the coefficient on $BAA - AAA$ is larger in these regressions than in the earlier ones. For these reasons, we concentrate on the long term corporate bond yield spreads in the rest of the paper.

Our results imply that an important part of the corporate bond spread is due to variation in the supply of Treasury securities, suggesting that the corporate bond spread has a significant "non-default" component. This result accords with some evidence from the finance literature on corporate bond pricing. In a recent analysis of corporate bonds using prices from the credit-default swap market, Longstaff, Mithal, and Neis (2005) conclude that the default component is important, but does not account for the entire corporate spread. They find evidence of a significant nondefault component ranging from about 20 to 100 *bps* depending

[12] We calculate an annual CP-Bills spread by annualizing 3-month yields, sampled quarterly, for the period 1972-2005 and annualizing 6-month yields, sampled semiannually, from 1921-1971. We annualize the yields by rolling over the investment at the end of each 3-month period (or end of each 6-month period prior to 1972) at the then prevailing yields. The specific data series used are as follows: The commercial paper data from 1972 to 2005 is from Global Insight, "INTEREST RATE: COMMERCIAL PAPER, 3-MONTH (PER ANNUM,NSA)." From 1921 to 1971 we use 6-month commercial paper data from John Campbell's web page (see page 8 of http://kuznets.fas.harvard.edu/∼campbell/papers/dataapp.pdf). The T-Bill data from 1972 to 2005 is from FRED's "3-Month Treasury Bill: Secondary Market Rate." From 1959 to 1971 the T-Bill data is from FRED's "6-Month Treasury Bill: Secondary Market Rate". From 1931-1958 the T-Bill data are from the NBER's series "U.S. Yields On Short-Term United States Securities, Three-Six Month Treasury Notes and Certificates, Three Month Treasury 01/1931-11/1969", and for 1921-1930 the T-Bill data are from the NBER's series "U. S. Yields On Short-Term United States Securities, Three-Six Month Treasury Notes and Certificates, Three Month Treasury 01/1920-03/1934."

[13] Commercial paper is not callable, while long-term corporate bonds are typically callable. Thus, the CP-Bills spread does not have a call option component as does the long term corporate bond yield spread. Moreover, the maturity of commercial paper and T-Bills can be exactly matched, while there may be some maturity mismatch between the Moody's AAA bond yield and the long term Treasury bond yield. It is encouraging that our results hold for the CP-Bills spread suggesting that the call option and maturity mismatch factors are not responsible for the correlation we document.

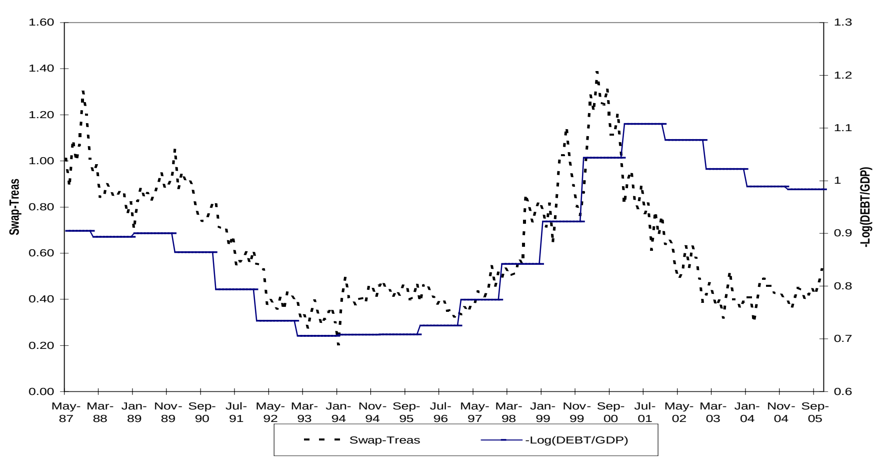
upon the bond. Other recent papers in the literature reach similar conclusions (see, for example, Elton *et al* (2001), Collin-Dufresne, Goldstein, and Martin (2001), or Huang and Huang (2001)). Our results not only confirm the existence of a non-default component over a long time period, but tie this non-default component to the supply of Treasury securities.

4.2 Swap Spread

The literature on interest rate swaps has prominently raised the possibility that there may be a convenience yield on Treasury securities (see Duffie and Singleton (1997), Grinblatt (2001), He (2001), Liu, Longstaff, and Mandell (2004), Li (2004), and Feldhutter and Lando (2005)).

Figure 4 graphs the 10-year US Dollar swap spread and the negative of the $log(Debt/GDP)$ ratio over the period from 1987 to 2005. The data is from Global Financial Data (series ISUSA10D). The 10-year US Dollar swap spread is the difference between the fixed rate in a 10-year fixed-for-floating interest rate swap and the yield on 10-year Treasury notes. We switch the sign on $log(Debt/GDP)$ following on our previous results that the two series are negatively correlated. The figure confirms the evidence reported in Figure 3 and Table I, albeit for a shorter, more recent, period.

Figure 4: Swap Spread and Government Debt



The 10-year interest rate swap spread (left y-axis)and $-log(Debt/GDP)$ ratio (right y-axis) are graphed from 1987 to 2005. The swap spread is monthly and measured as a percentage, while the Debt/GDP ratio is annual.

A 10-year interest rate swap is a string of forward contracts between today ($s = t$) and $s = t+10$ years.

The payment on date s is equal to $R^s - \tilde{r}_s$, where R^s is the fixed interest rate known as the 10 year swap rate, and $\tilde{r}_s$ is a variable interest rate that is set at a date just prior to date s. The variable or floating interest rate is indexed to LIBOR, and the reset frequency as well as the frequency of swap payments can range from overnight to one-year. A typical swap contract may be indexed to 3-month LIBOR and require payments every 3 months for 10 years.

The LIBOR rate itself reflects the borrowing rate for a AA rated financial institution. Thus, ignoring the uncertainty in the realized path of LIBOR rates for the next 10 years, the 10 year swap rate (R^s) is roughly equal to the 10 year interest rate at which a financial institution that is sure to be AA rated for the next 10 years will borrow (Collin-Dufresne and Solnik (2001)). LIBOR rates are typically slightly higher than Federal Funds rates and the borrowing rates on short-term collateralized loans (the repo rate).

Using sophisticated pricing models that incorporate estimates of default rates as well as risk premia due to the uncertainty in realized LIBOR rates, the current literature finds that there is a large unexplained component of the swap spread (see Duffie and Singleton (1997), Grinblatt (2001), He (2001), Liu, Longstaff, and Mandell (2004), Li (2004), and Feldhutter and Lando (2005)). Feldhutter and Lando (2005), studying a sample from 1997 to 2003, find that the default component of swap spreads averages around 40 *bps*. He (2001) notes that the spread between LIBOR rates and repo rates average between 15 and 25 *bps*, occasionally reaching highs of 40 *bps*. As one can see in Figure 4, swap spreads are typically much higher than 40 *bps*. Thus, the weight of evidence in the interest rate swap literature points to a substantial nondefault component in the swap spread.

Table II presents results analogous to Table I, but using the 10-year interest rate swap spread as dependent variable. We note that these results are for only 19 data points, so their importance should be weighted accordingly. In the majority of the specifications, the results point to a significant role for the supply of Treasury securities as a driver of swap spreads.[14] Note also that the coefficient on the credit risk variable ($BAA - AAA$ spread) is barely significant, and has the wrong sign in Panel B. This result accords with the existing literature which finds only a secondary role for default risk in swap spreads. The magnitudes on $log(Debt/GDP)$ are larger in many of the swap spread regressions as compared to the corporate bond spread regressions. These results suggests that the swap spread, since it is less affected by other factors, may be an ideal measure of the value investors assign to Treasury securities.[15]

[14]Our finding that the aggregate supply of Treasury securities affects the swap spread is distinct from the finding of Johannes and Sundaresan (2006) that collateralization requirements on individual swap counterparties affects the prices of swaps.

[15]Like the CP-Bills spread, the interest rate swap spread is an exact maturity match and has no call option component. That our results hold for the swap spread is further support that our results are not driven by a spurious correlation.

4.3 Bond Returns

In this subsection we present regressions using the realized return on corporate bonds relative to Treasury bonds as dependent variable. By using realized returns we bypass any problems arising from the fact that the corporate bond yield spread partly reflects the default risk of corporate issuers. That is, since return realizations encompass default events, including corporate bond downgrades, they only measure the economic risk premium and the non-default component of the relative pricing of corporate bonds and Treasury securities. However, this measure does come at a cost: realizations are random, and thus realized excess returns are a noisy estimate of the non-default component.

Table III-A presents regressions relating the realized excess returns to the ex-ante yield spread between corporate and Treasury bonds. The dependent variable in the Table III regressions is the percentage excess return on long term corporate bonds over long term government bonds, at one, three, and five year horizons. The return data are from Ibottson, and are annual, beginning in 1926 and ending in 2004. The Ibbotson corporate bond index is based on the total return from holding high grade (typically AAA and AA) corporate bonds with approximately a 20-year maturity. AAAs and AAs almost never default over the next year. The default-events in holding these bonds is that the probability of default rises (for example, downgrades) and the bonds deliver a low return. The latter is the relevant default risk in holding high grade corporate bonds over a short period. If a bond is downgraded during a particular month, Ibbotson includes its return for that month in the computation of the index return before removing the bond from future portfolios.

In addition to the corporate bond spread, we include the slope of the yield curve as independent variable. *slope* captures the state of the business cycle, and any possible time variation in investor risk aversion that may drive expected returns on risky assets. The results confirm that the bond yield spread predicts future excess returns, and is thereby not purely reflective of default considerations. These results support our use of the bond spread as dependent variable in the prior regressions.

Table III-B presents regressions analogous to Table I, but using the realized excess return (rather than the corporate bond yield spread) as dependent variable. Relative to Table III-A, we consider two additional independent variables. *durationhedge* is the realized returns on long term government bonds over short term bonds, and is meant to capture any possible biases due to differences in duration of the underlying corporate bonds and Treasury bonds. We also include the standard four factor controls (market, HML, SMB, momentum) to proxy for other risk factors driving asset returns.[16]

[16]The fact that corporate bonds offer a higher return than Treasury bonds raises the standard arbitrage question of why an investor who has no convenience demand for Treasuries does not short Treasuries and purchase corporate bonds, and thereby eliminate the return differential. To engage in this transaction, the arbitrageur needs to borrow Treasury securities through a repurchase agreement and short the bonds. He borrows Treasury bonds, leaving cash with the bond lender to cover the value of the Treasury security, and then sells the bonds in the market (see Krishnamurthy, 2002, for a description of the repurchase market). Note that the cash proceeds from the short must be left with the bond lender as security for borrowing the bonds,

The results largely accord with our previous findings. The $log(Debt/GDP)$ ratio is negatively related to realized returns. Our strongest results are at the three-year and five-year horizons. This may reflect that the Debt/GDP ratio picks up low frequency movements in the convenience yield on Treasury securities. The magnitudes reported for the semi-elasticity are also in line with our previous findings. If we divide the coefficient estimate on $log(Debt/GDP)$ of Table III-B by the coefficient estimates on $AAA - Treasury$ from Table III-A (to convert back into yield equivalents), we arrive at numbers around -1 which are similar to estimates from previous tables.

4.4 Treasury Substitutes

Our results so far suggest that the demand curve for Treasury securities is downward sloping, consistent with Figure 1 and 2. We argue that this is because investors assign a convenience value to Treasury securities which lowers their yield relative to corporate securities with similar cashflow properties, and this value rises as the stock of Treasury debt falls.

As the stock of Treasury debt falls, we would expect that investors substitute some of their demand into other low risk securities that may offer some, but perhaps not all, of the convenience service of Treasury securities. That is, agent utility functions are likely to be:

$$u(c_t) + \beta^\tau u(c_{t+\tau}) + v(\theta_t^T, \theta_t^S; X_t),$$

where θ_t^S are Treasury substitutes, with $\frac{\partial^2 v}{\partial \theta_t^T \partial \theta_t^S} < 0$ and $\frac{\partial v}{\partial \theta_t^S} > 0$. Such substitutes may include high grade corporate bonds and agency debt. Then, as θ_t^T falls, agents will bid up the price of substitute securities. We present results consistent with this prediction based on corporate bonds. Our regressions do not exploit changes in the supply of corporate debt – such changes are likely to be endogenous to the corporate bond spread – but only exploit changes in the supply of Treasury debt.[17]

In Table IV-A, we use the BAA-AAA yield spread as the dependent variable and regress this measure against $log(Debt/GDP)$ with various controls. Note that these regressions do not control for default risk, but as we have seen in earlier regressions, the results are not altered by the inclusion of a default risk control.

In Table IV-B, we redo our main regressions but now use the $BAA - Treasury$ spread as dependent variable. Since the results of Table IV-A suggest that the AAA rate is also affected by changes in the

and cannot be used to directly purchase corporate bonds. To go long the corporate bonds, the arbitrageur must purchase a corporate bond, borrowing cash against the corporate bond in the repurchase market. There are limits to carrying out this arbitrage. First, the repo market on corporate bonds is quite limited, involving large capital requirements and expensive repo rates. Moreover, the arbitrageur will also have to post capital in order to short the Treasury bonds. Together these obstacles will limit carrying out the arbitrageur's strategy.

[17] We can add the ratio of corporate debt to GDP as regressor to investigate how it correlates with the corporate bond spread. We find that the coefficient on this covariate is small and not statistically significant.

supply of Treasury debt, the regressions using the $AAA - Treasury$ spreads underestimate the slope of the Treasury demand curve. Consistent with this statement, we find that the coefficient estimates in Table IV-B are roughly twice as large as those reported in Table I-A.

5 Demand Curves, by Group

Using a variety of measures, we have shown that the aggregate demand curve for Treasury debt is downward sloping. We have argued that the demand curve is not perfectly elastic because Treasury securities provide a convenience service. We next turn to analyzing disaggregated data from the Flow of Funds Accounts of the Federal Reserve to shed some light on the sources of this convenience demand. We first argue that different groups of Treasury owners likely have different motives for holding Treasuries. We then estimate which groups have the least elastic demand curves in order to determine which of the various motives are likely to contribute substantially to the convenience yield on Treasuries.

5.1 Who Holds Treasury Debt and Why?

Table V presents statistics on the fraction of Treasury securities held by different groups in the economy. The data are from Table L.209 in the Flow of Funds Accounts of the Federal Reserve. They are annual from 1945 to 1951. From 1952 onwards the data are quarterly, and we use the values for the end of the second quarter. Table V presents the average fraction of Treasury holdings across these years.[18]

The mean holdings reported in the second column gives a rough idea of which groups are important in setting the prices of Treasury securities. There are two groups with strong trends, for which the means are misleading. The Foreign Official Holdings (i.e. central banks) category is an important recent holder of Treasury securities. This group's holdings rise in 1971 with the abandonment of the Bretton Woods system. The maximum holding of 0.29 is in 2005. The Banks/Credit Institutions group has its maximum holdings of 0.42 in 1945, which subsequently decreases in the 1950s and 1960s. The Fed-Treasury Accord (Wicker, 1969) incentivized banks to hold Treasury securities during World War II because the Fed, in pegging Treasury interest rates, had agreed to allow the private sector to freely exchange Treasury securities for reserves.

We offer three motives behind the Treasury holdings, reflected differently across the groups in Table V. First, a number of observers have noted the superior liquidity of Treasury securities over other assets such as corporate bonds. For example, Reinhart and Sack (2000) note that bid-offer spreads on corporate bonds

[18] For simplicity, Table V omits a few small categories of Treasury owners. The omitted categories are nonfinancial corporate business, nonfarm noncorporate business, Federal government retirement funds (for whom reported holdings of Treasuries are zero up to 1986), government-sponsored enterprises, and brokers and dealers. The total share of Treasuries owned jointly by these groups averages 4.8% with a maximum of 8.9% and a minimum of 1.3%

are four to six times larger than those of Treasury bonds. Krishnamurthy (2002) shows that the spread between commercial paper and Treasury bills is highly correlated with the spread between more and less liquid Treasury securities. Krishnamurthy suggests that the comovement in spreads reflects economy-wide variation in agents' desire to hold liquid securities. Changes in agents' demand for liquidity drives both the liquidity spreads within the Treasury market as well as the spread between less liquid commercial paper and Treasury securities. These observations suggest that a *liquidity motive* is an important factor driving Treasury holdings. Managers of large reserve positions (foreign central banks, Federal Reserve banks) and those with short-term liquidity needs (households, banks and credit institutions) are likely to purchase Treasuries because of their superior liquidity. Banks and credit institutions also face capital requirements that favor the liquidity/low risk of Treasury securities over other assets.

Second, Kohn (2005) notes that Treasury securities best satisfy the Federal Reserve's portfolio objective of "liquidity, safety, and neutrality in private credit allocation." A *neutrality motive* is important for governmental holders of Treasury securities (including foreign central banks and state/local governments). Were these entities to invest in private assets, questions arise about which particular private assets to choose, the possibility of sub-optimal speculation/ mis-management arises, etc. Thus, an implicit mandate of avoiding investments in private assets may be in the best interests of taxpayers for these governmental entities.

Third, Treasury securities carry a halo of surety that may motivate the holdings of some groups. For example, unsophisticated households who are unable to assess the risk in corporate assets may be drawn to Treasuries by a *surety motive* (see Vissing-Jorgensen, 2002, on costs that may limit household participation in the stock market). The same motive may apply to some of the foreign private sector's demand for Treasury securities. Desiring to hold assets in US Dollars, some foreign investors may choose to hold the dollars in the form of Treasury securities rather than corporate assets.

State/local retirement funds, private pensions, and insurance companies are an interesting group for our analysis. Since these groups have a long-term objective and no explicit regulatory requirements, the liquidity and neutrality motives are unlikely to be important for them. Comparing the demands of groups that are driven by liquidity and neutrality motives (i.e. official groups, banks, and households) to that of the long-term investors provides a gauge as to the importance of the liquidity and neutrality motives. As we show below, we find that the long-term investor groups have the most elastic demand curves (as well as smallest mean holdings from Table V). This points us to the conclusion that the liquidity and neutrality motives are the primary determinants of the convenience yield.

It is difficult to say exactly why state/local retirement funds, private pensions, and insurance companies hold any Treasuries at all. One possibility is that the surety motive applies indirectly to these groups. Insurance companies' business depends on the perception by their customers of a stable balance sheet. If these customers think that balance sheet stability is enhanced by holdings of Treasury securities, insurance companies may demand Treasuries. A similar argument can be applied to the retirement saving groups who make defined benefit promises to their claimants.

Our strategy in this section is to estimate demand curves for each of the groups of Table V. We assume that group-i's demand can be expressed in the same log-linear functional form as earlier specifications:

$$S_t = A^i + B^i log(\theta_t^i/GDP_t) + C^i\ Y_t + \epsilon_{i,t}. \tag{5}$$

We are interested in estimating B^i, the demand elasticity for group-i. The demand elasticities can help to shed light on which of the groups – and indirectly, which of the motives – are important in determining the convenience yield.

5.2 IV Using Total Stock of Debt

In equilibrium, shocks to group i's demand will affect both the spread and group i's holdings. This implies that in (5) both S_t and θ_t^i are endogenous and correlated with $\epsilon_{i,t}$. Thus, we cannot estimate B^i in (5) using OLS and need an instrument to proceed. As we explain next, we use the total stock of Treasury debt as an instrument.

We rewrite (5) to express the quantity as a function of price:

$$log(\theta_t^i/GDP_t) = \alpha^i + \beta^i S_t + \gamma^i Y_t + e_{i,t},$$

where the constants are defined appropriately and $e_{i,t} = -\epsilon_{i,t}/B^i$. Summing the left and right hand side of this equation across all groups, $i = 1...N$, and dividing both sides by N, we find

$$log\left(\theta_t^1 \times \theta_t^2 \times \cdot \cdot \theta_t^N\right)^{1/N} - logGDP_t = \sum_i \frac{\alpha^i}{N} + S_t \sum_i \frac{\beta^i}{N} + Y_t \sum_i \frac{\gamma^i}{N} + \sum_i \frac{e_{i,t}}{N}. \tag{6}$$

The market clearing condition for Treasury debt implies,

$$\sum_i \frac{\theta_t^i}{N} = \frac{\Theta_t^T}{N}.$$

Because we have assumed a log-linear demand curve for each group, the left hand side of (6) involves the product of each of the group's holdings of Treasuries. However, if we make the approximation that the geometric average of holdings is equal to the arithmetic average of holdings:

$$\left(\theta_t^1 \times \theta_t^2 \times \cdot \cdot \theta_t^N\right)^{1/N} \approx \sum \frac{\theta_t^i}{N} = \frac{\Theta_t^T}{N},$$

we can rewrite (6) as

$$S_t = A + B\ log(\Theta_t^T/GDP_t) + C\ Y_t + D \sum e_{i,t}. \tag{7}$$

A, B, C, and D are functions of the sums of the demand coefficients across the groups.[19] The approximation error involved becomes larger if the holdings are more dissimilar across groups. If we use the mean holdings of each group from Table V, the geometric average is 10.6% and the arithmetic average is 8.0%.

Equation (7) is the demand curve we have estimated in earlier sections. The derivation makes clear that S_t is indeed a function of $e_{i,t}$ (and $\epsilon_{i,t}$), consistent with our earlier remark about needing an instrument. If we assume that changes in the stock of Treasury debt (Θ_t^T) are not correlated with unobserved shifts ($\epsilon_{i,t}$) in a group's demand for Treasury bonds, beyond the controls of our regressions, then Θ_t^T can be used as instrument to estimate equation (5). In words, shifts in the total stock of debt shift the supply curve facing group-i, and can thereby be used to trace out group-i's demand curve.

We use two stage least squares (2SLS), instrumenting $log(\theta_t^i/GDP_t)$ with $log(\Theta_t^T/GDP_t)$. In the first stage we regress $log(\theta_t^i/GDP_t)$ on $log(\Theta_t^T/GDP_t)$ and Y_t. We use the fitted values to estimate the group's demand curve:

$$S_t = A^i + B^i \; log(\widehat{\Theta_t^i/GDP_t}) + C^i \; Y_t + \epsilon_{i,t}. \tag{8}$$

Table VI presents estimates of the semi-elasticity B^i for each of the groups. The controls (Y_t) in this regression include the $BAA - AAA$ spread and *slope*. We also include a time trend as a control in these regressions because the holdings for many of the groups contain strong trends (the foreign official holders and banks/credit institutions as noted above). Finally, note that the sample period for these regressions begins in 1945, because the group holdings data is from the Flow of Funds Accounts of the Federal Reserve, which are only available beginning in 1945.

There is a clear ranking in the demand elasticities across the categories. Groups like Private Pensions and Insurance Companies have much more elastic demand curves than groups like Federal Reserve Banks, Foreign Official Holdings or State/Local Governments. The former groups make larger changes in their holdings of Treasury securities in response to a change in the corporate bond spread generated by a shift in the total supply of Treasuries. In other words, when the total supply of Treasuries shifts, the equilibrium holdings of groups with more elastic demand curves change more. This can be seen directly in the first stage of the IV estimation which is also shown in Table VI.

The most inelastic groups are the governmental holders of Treasury securities (Federal Reserve Banks, Foreign Official Holdings, State/Local Governments). These groups are also among the largest holders of Treasury securities. This suggests that the neutrality and liquidity motives are principal determinants of the convenience yield. Banks/Credit institutions follow closely behind the governmental groups in the inelasticity of demand. As noted earlier, this group is driven by the liquidity motive.

If the convenience yield is driven mainly by the neutrality and liquidity motives then we would expect

[19] We do not impose the restrictions that A, B and C are functions of the group demand coefficients because of the approximation error we have introduced in aggregating the demand curves across groups.

that groups for which these motives matter less should have the most elastic Treasury demands. This is what we find. The groups with more elastic demands are the Households and Mutual Funds, the Foreign Private Sector, and the long-term investor groups (State/Local Retirement Funds, Private Pensions, and Insurance Companies). The Households and Mutual Funds and the Foreign Private Sector fall in the middle of the ranking of demand elasticities. These groups are motivated by a combination of the liquidity and surety motive. The most elastic demanders are the long-term investor groups, who we know are not affected by the liquidity and neutrality motives and are probably indirectly driven by the surety motive of their claimants. These observations suggest that the surety motive is secondary to the liquidity and neutrality motives in determining the convenience yield.

5.3 IV Using Foreign Official Holdings and Stock of Debt

In the first stage of the IV estimation reported in Table VI, the ability of $log(Debt/GDP)$ to explain movements in groups' Treasury holdings differs across groups. The t-statistics are the lowest for Federal Reserve Banks and Foreign Official Holdings, suggesting that a substantial fraction of the variation in these groups' holdings are generated by other factors. If these other factors are exogenous in the sense of being uncorrelated with shocks affecting other (more elastic) groups' demand, then holdings of Federal Reserve Banks and Foreign Official Holdings can serve as additional instruments for the estimation of the other groups' demand curves, over and above the instrument used above (the total supply of Treasuries).

Importantly, the availability of several instruments allows us to perform tests of the overidentifying restrictions in order to test the validity (exogeneity) of the instruments. In what follows we focus on two instruments, total Treasury supply and Foreign Official Holdings. Tests of overidentifying restrictions rejected Federal Reserve Bank holdings as a valid instrument, but did not reject the Foreign Official Holdings as a valid instrument (see Table VII).

We note that on a priori grounds, this is what one may expect. Federal Reserve Holdings are driven by monetary policy which is likely to be correlated with US demand conditions. On the other hand, changes in the reserve holdings of foreign central banks are largely driven by capital inflows into foreign countries and the exchange rate policies of these countries, which are plausibly exogenous to US demand conditions. If foreign central banks hold their dollar reserves in Treasury securities[20], then changes in the capital account will lead to changes in foreign central banks' holdings of Treasury securities and changes to the equilibrium in the Treasury market.

We rewrite equation (6) to reflect the Foreign Official Holdings (FOH):

$$log\left(\theta_t^1 \times \theta_t^2 \times \cdot\cdot \theta_t^N\right)^{1/N} - logGDP_t = \frac{1}{N}log(\theta_t^{FOH}/GDP_t) + \sum_{i \neq FOH} \frac{\alpha^i}{N} + S_t \sum_{i \neq FOH} \frac{\beta^i}{N} + Y_t \sum_{i \neq FOH} \frac{\gamma^i}{N} + \sum_{i \neq FOH} \frac{e_{i,t}}{N}$$

[20] In practice, foreign central banks hold the dollar reserves in Treasury securities and Agency securities.

Then, approximating the geometric average with the arithmetic average we have,

$$S_t = A_1 + B_1 \ log(\Theta_t^T/GDP_t) + B_2 \ log(\theta_t^{FOH}/GDP_t) + C_1 \ Y_t + D_1 \sum_{i \neq FOH} e_{i,t}. \tag{9}$$

If we assume that changes in θ_t^{FOH} are uncorrelated with $e_{i,t}$ ($i \neq FOH$), given the controls, then $log(\theta_t^{FOH}/GDP_t)$ can be used as a second instrument for the demand system.

We use 2SLS to estimate group i's demand curve using $log(\Theta_t^T/GDP_t)$ and $log(\theta_t^{FOH}/GDP_t)$ as instruments. In the first stage, we regress $log(\theta_t^i/GDP_t)$ on $log(\Theta_t^T/GDP_t)$ and $log(\theta_t^{FOH}/GDP_t)$, as well as controls Y_t. The controls Y_t include the $BAA - AAA$ spread, *slope* and a time trend. The fitted values are used to estimate the demand curve:

$$S_t = A^i + B^i \ log(\widehat{\Theta_t^i/GDP_t}) + C^i \ Y_t + \epsilon_{i,t}.$$

Table VII, Panel A presents the first stage estimates. The coefficient estimates on $log(\Theta_t^T/GDP_t)$ is positive for all groups, and the coefficient estimate on $log(\theta_t^{FOH}/GDP_t)$ is negative for most groups. An increase in the total stock of Treasuries is a rightward shift of the supply curve facing a group. Thus we would expect that the coefficient on total stock is positive. The second coefficient estimate should be negative because as FOH hold more Treasury securities, the residual supply facing a group shifts leftward. Note that group i's holdings are not equal to total supply less FOH holdings (this relation only holds for the sum over all groups). Thus, the sign patterns in the first-stage regressions are not driven by some mechanical relation (indeed they do not hold for two of the groups).

Table VII, Panel B presents the estimates of the slope of the demand curve, by group. The slope estimates are similar to those reported in Table VI.

Because these regressions have two instrumental variables, the demand systems are overidentified and we can test the validity (exogeneity) of the instruments. The last column in Panel B reports the p-values from the test of the overidentifying restrictions. The p-values are high in all but one case, confirming that our instruments are not endogenous. Note that this result is also comforting for the regressions we reported in the previous section, where we only used total stock of government debt as an instrument.

5.4 Change in Demand

Over the last 60 years, foreign holders of Treasuries have increased their holdings from 1% to 45% of the stock of Treasuries. The largest change is due to foreign official holders who have increased their holdings from 1% to 29%. Over the same period, banks and credit institutions have decreased their holdings from 42% to 3% while insurance companies have decreased their holdings from 9% to 3%. These patterns suggest a shift over time in the composition of Treasury holders from more elastic holders to less elastic holders, perhaps causing the aggregate demand for Treasuries to steepen over time.

Table VIII presents results for the corporate bond spread regressions and the CP-Bills spread regression, broken down by subsample. The breakpoint is 1971, which is the year when the Bretton-Woods system was abandoned. The foreign official holdings increase markedly beginning in 1971, and thus the abandonment of the Bretton-Woods system is a natural breakpoint for the sample.

Consistent with our conjecture that the demand curve has steepened over time, the slope coefficients are uniformly higher in the later period than in the earlier period. The coefficients are also significant and of the same order of magnitude as in previously reported regressions. Since the samples are short, we only introduce the $BAA - AAA$ spread control in these regressions.

6 Exponential Specification

Thus far we have reported regressions for log-linear specifications involving $log(Debt/GDP)$. As Figure 1 illustrates, the relation between the corporate bond yield spread and the $Debt/GDP$ ratio should involve an asymptote: the spread should asymptote to a non-negative number as $Debt/GDP$ becomes large. This asymptote can be interpreted as the part of the spread that is due purely to default, risk premium, and tax differences between AAA corporate bonds and Treasuries, rather than a convenience yield on Treasuries. The $log(Debt/GDP)$ specification implies that the spread will become negative for sufficiently large $Debt/GDP$ ratios. In this section we estimate a regression specification with the property that the spread asymptotes to a non-negative constant.

We consider the following exponential specification:[21,22]

$$S_t = b_0 + b_1 e^{b_2 \times (Debt/GDP)} + c \times Y_t + \epsilon_t.$$

Table IX reports the results. Column (1) reports the results where we suppress the constant term (i.e. $b_0 = 0$). Column (2) includes the constant term, and column (3) present results where we introduce the controls we have considered in other regressions. The controls are the $BAA - AAA$ spread and the slope

[21] We have also considered a specification where the $Debt/GDP$ term is $b_1(Debt/GDP)^{b_2}$. The latter specification yields a worse fit.

[22] The exponential specification can be motivated structurally as follows. Suppose that,

$$v'(\cdot) = e^{-\beta_1 \Theta_t^T + \beta_2 GDP_t} \quad \text{and,} \quad u'(\cdot) = e^{-\alpha c_t}$$

then,

$$v'(\cdot)/u'(\cdot) = e^{-\alpha c_t \frac{GDP_t}{c_t}\left(\frac{\beta_1}{\alpha}\frac{\Theta_t^T}{GDP_t} + \frac{\beta_2}{\alpha} - \frac{c_t}{GDP_t}\right)}.$$

Note that αc_t is the coefficient of relative risk aversion, γ_t. If take γ_t as well as c_t/GDP_t to be approximately constant over time than we can write,

$$v'(\cdot)/u'(\cdot) \simeq b_1 e^{-\left(\gamma \frac{GDP}{c}\frac{\beta_1}{\alpha}\right) \times \Theta_t^T / GDP_t}$$

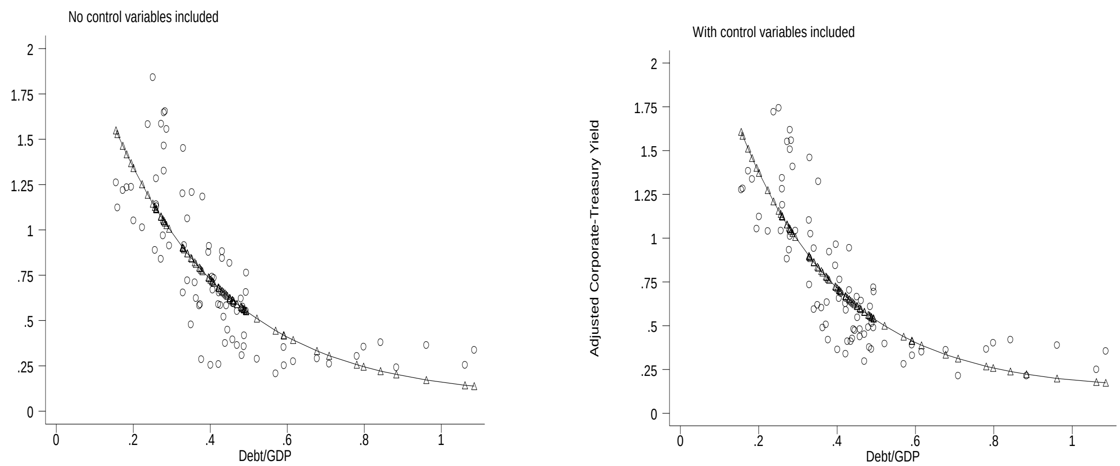
which is the specification we adopt.

of the yield curve (*slope*). The control variables have been demeaned so that b_0 can be interpreted as the asymptote value of the corporate bond spread.

The results are consistent with intuition. b_2 is negative to fit the inverse relation between the yield spread and the $Debt/GDP$ ratio. b_0 is small, but positive, consistent with the point we have noted about the spread asymptoting to a positive value.

The asymptote values are 7 *bps* and 13 *bps* (although not statistically different from zero). Our results thus suggest that the default, risk premium, and tax component of the spread is small, which seems plausible given the existing literature on corporate bond valuation. For example, Elton *et al* (2001) consider actual default rates and bankruptcy recovery rates on AAA corporate debt and show that a risk neutral investor will require at most 5 *bps* default premium to buy a 10 year corporate bond. Taking into account the differential state tax treatment of corporate and government bonds (see Section 8.2) can increase this spread to at most 35 *bps* according to Elton *et al* (2001)'s calculations.

Figure 5: Exponential Specification of Demand Curve



The figure on the left presents a scatter plot of the corporate bond yield spread (y-axis)and the $Debt/GDP$ ratio (x-axis), using annual data from 1925 to 2005. Also pictured in the figure are the predicted values from the exponential specification of the relation between the yield spread and Debt/GDP ratio. The figure on the right presents a similar result, but presenting the predicted values from the exponential specification including controls. The corporate bond yield spread (y-axis of right panel) is adjusted to remove the effect of the control variables.

Figure 5 presents the results of the exponential specification in graphical form. The figures plot the predicted values of the spread from the specification with and without controls of Table IX. Also pictured are scatter plots of the corporate bond yield spread (y-axis) and the $Debt/GDP$ ratio (x-axis). The corporate bond yield spread in the righthand panel of the figure (y-axis of right panel) is adjusted to remove the effect of the control variables.

7 Implications

The main finding of this paper is that the demand curve for convenience provided by Treasury debt is downward sloping. In earlier sections of the paper, we have discussed the implications of this finding for corporate bond pricing and the interpretation of the spread between corporate bond and Treasury bond yields. We have also argued that the liquidity motive is likely to be one of the main drivers of the convenience yield on Treasuries. In this section, we first use our estimates to quantify the aggregate value of liquidity/convenience to investors. We then discuss the implications of our findings for some other important issues in finance and macroeconomics.

7.1 Value of Treasury Liquidity/Convenience to Investors

Investors purchase Treasury securities despite the fact that these securities offer a low return because they convey liquidity/convenience benefits. In this subsection we quantify the total annual value that investors place on the benefits of Treasuries. Because of the evidence that AAA corporate bonds are substitutes for Treasury debt, this total annual value is a lower bound on the value of aggregate bond market liquidity to investors.

Table X presents the results. We ask how much investors will pay, as a yearly flow cost (percentage of GDP), in order to enjoy the benefits of a particular level of Treasuries/GDP, starting from a scenario with a Treasury/GDP ratio of zero. The calculations are based on the exponential specification with $b_0 = 0$, $b_1 = 2.5$ and $b_2 = -3.3$. We set b_0 to zero in order to focus only on the benefits of Treasuries as opposed to the default, risk premium, and tax component of the corporate bond spread. Results are shown for different values of relative risk aversion.

The first number in the third column is 0.19%. The interpretation of this number is that investors with a relative risk aversion of one will pay 0.19% of GDP every year in order to enjoy the benefits of having a Treasury/GDP ratio of 0.10. To compute this number, we ask how much consumption agents will be willing to forgo in order to increase Θ^T/GDP from $\Theta^{T,0}/GDP = 0$ to $\Theta^{T,1}/GDP = 0.10$. Thus we solve for δ, where

$$v(\Theta^{T,1}, GDP) - v(\Theta^{T,0}, GDP) = u(c) - u(c - \delta \times GDP).$$

The computation is based on integrating our estimate of $v'(\Theta^T; GDP)/u'(c)$ over Θ^T/GDP, using the function $b_1 e^{b_2 \Theta^T/GDP}$ as $v'(\Theta^T; GDP)/u'(c)$.[23]

Of particular interest is the value investors place on the current stock of Treasuries. The Debt/GDP ratio is currently about 0.38. Across the different values of relative risk aversion, the value investors put on this amount of aggregate liquidity is between 0.21% and 0.54% of GDP per year. With US GDP for 2005 at $12.5 Trillion, this corresponds to between $26 and $68 Billion in benefits for the year 2005. Finally, we note that these figures are flow benefits that are enjoyed annually. As a back-of-the-envelope calculation, if we take the present value of a $26 billion ($68 billion) real perpetuity at a real discount rate of 2%, the stock value of the benefit is $1.3 trillion ($3.4 trillion).

The numbers from Table X also shed light on the cost of aggregate liquidity contractions to investors. Many accounts of financial crises emphasize that negative shocks to financial intermediaries decrease their ability to maintain the continuous trading liquidity of asset markets, and thereby reduce the liquidity of financial assets (see, for example, Caballero and Krishnamurthy, 2006). As the liquidity of all assets falls, the aggregate pool of liquid assets available to investors shrinks. This scenario – a disintermediation induced reduction in aggregate liquidity – is costly to investors. If we make the identifying assumption that a reduction in aggregate liquidity caused by disintermediation is similar to a reduction in aggregate liquidity caused by a decline in Treasury debt issuance, we can use our estimation results to evaluate the cost of aggregate liquidity contractions. From Table X we see that if aggregate liquidity falls from 1 to 0.3, the consumption flow cost of this fall ranges from 0.06% of GDP to 0.25% of GDP.

[23] We have assumed a utility function with arguments $u(c) + v(\Theta^T/GDP)$. The first order condition from this utility function implies that the convenience yield, in terms of the bond yield spread, is equal to,

$$\frac{1}{u'(c)} \frac{\partial v(\Theta^T/GDP)}{\partial \Theta^T} \equiv G(\Theta^T/GDP)$$

The regressions we present use the bond yield spread as dependent variable and Θ^T/GDP as independent variable. Thus these regressions estimate the function $G(\Theta^T/GDP)$. To use the regression estimates to make the relevant computation, we define $D = \Theta^T/GDP$, so that $\frac{dv(D)}{dD} = GDP \times G(D)u'(c)$. Then,

$$v(D^1) - v(D^0 = 0) = GDP \times u'(c) \int_{D_0=0}^{D_1} G(D)dD$$

Our definition of δ is,

$$v(D^1) - v(0) = u(c) - u(c - \delta \times GDP) \approx u'(c)\delta \times GDP - \frac{1}{2}u''(c)(\delta \times GDP)^2$$

Thus,

$$\int_0^{D_1} G(D)dD = \delta \left(1 - \frac{1}{2}\frac{u''(c)}{u'(c)}\delta \times GDP\right) = \delta \left(1 + \delta \frac{\gamma}{2} \frac{GDP}{c}\right),$$

where γ is the coefficient of relative risk aversion. We report δ for various values of γ and a value of GDP/c of 1.5 in the table. $G(D)$ is the function we estimate and is in units of percent per year. Thus δ is in units of percentage of GDP per year.

7.2 Value of Convenience to Taxpayers

Because investors value the convenience features of Treasuries, the US Treasury is able to sell Treasury bonds at a premium. We have argued that this is a key driver of the substantially lower yield on Treasuries than on AAA corporate bonds. It is interesting to evaluate how much taxpayers benefit from being able to finance the US federal debt with securities that have special benefits to investors.

As a simple partial equilibrium calculation, consider how large the convenience yield is at the current Debt/GDP ratio based on our exponential specification (with b_0 set to zero): Using $b_1 = 2.5$ and $b_2 = -3.3$ the convenience yield component of the spread is $2.5e^{-3.3\times 0.38} = 0.71$ percentage points. Therefore, the yield on Treasuries would be about 71 bps higher if Treasuries did not provide convenience benefits over and above AAA corporate bonds. That would imply increased interest expenses of $0.71 \times 0.38 = 0.27\%$ of GDP per year, assuming the Debt/GDP ratio was kept constant at 0.38.

To put this number in perspective, consider the benefits taxpayers enjoy from households' willingness to hold fiat money at no interest. The monetary base at the end of 2005 was $787 Billion, corresponding to 6.3% of GDP. Suppose the federal government had to repurchase the monetary base by issuing Treasury bills and that these Treasury bills had a 5% nominal yield. Then the annual interest expense to taxpayers of this additional debt would be $5 \times 0.063 = 0.32\%$ of GDP per year.

Together, these calculations suggest that the annual benefit to taxpayers from being able to finance the current level of debt with securities that have a convenience yield are about as large as the annual benefit to taxpayers resulting from the public's willingness to hold money at no interest.

7.3 The Effect of Foreign Official Demand on Treasury Yields

Some recent papers in international finance argue that the US government has a special ability to supply financial assets to the world's savers (see Caballero, Farhi, and Gourinchas (2006), and Dooley, Folkerts-Landau and Garber (2003)). These papers tie the US current account deficit to the demand for US assets by foreign savers (see also Bernanke (2005)).

Our finding that the demand for Treasury debt from foreign official holders is very inelastic is consistent with these theories. Our estimates of the slope of the Treasury demand curve also offers some insight into the interest rate effect of the demand by foreign investors. If foreign official investors exit the US Treasury market, they will sell roughly 29% of the debt back to US investors. Based on the log-linear demand curve we estimate, the sale will raise Treasury yields, relative to corporate bond yields, by between 19 *bps* and 55 *bps*. Using the exponential demand curve gives a value of 31 *bps*.

We arrive at these numbers as follows. Currently the Debt/GDP ratio is 0.38 of which foreign official investors own 0.11 and the rest of investors own 0.27. If foreign official investors sell their 0.11, then the rest of investors have to increase their holdings to 0.38. We have shown that foreign official investors have inelastic demand curves for Treasury debt. Thus the slope of the aggregate demand curve for Treasury convenience must reflect the preferences of the rest of investors. We evaluate our estimated aggregate demand curve at points 0.27 and 0.38, computing the difference in the convenience yield between these points to arrive at the numbers we present. The range for the log-linear estimate comes from using estimates from Table I-A, Panel B, column (2) and Table IV-B, column (2). For the exponential demand case we use $b_1 = 2.5$ and $b_2 = -3.3$.

7.4 Benefits to Retirement Savers from Investing in Corporate Bonds

Our results suggest that investors who purchase Treasuries earn a substantially lower yield than they would earn had they instead purchased AAA corporate bonds. Indeed, our exponential specification implies that only $7 - 13$ *bps* of the yield spread between AAA corporate bonds and Treasury bonds is compensation for risk and tax treatment. The bulk of the spread is (negative) compensation for the liquidity and neutrality features of Treasuries.

Therefore, investors who do not place much value on the liquidity features of Treasuries would be better off buying AAA corporate bonds than Treasury bonds. As an example, consider a conservative investor who is saving for retirement. Suppose the investor is 30 years old, plans to invest $15,000 for retirement at the end of each year up to age 60, and expects to live to age 80. If the investor invests in Treasuries with an expected real return of 2% (say), then the annual real consumption per year in retirement will be $37,215. If the investor instead invested in AAA corporate bonds and earned an extra 0.71% in annual return (our estimate of the convenience yield on Treasuries at the current Debt/GDP ratio), then the person could enjoy an annual real consumption of $44,557 per year in retirement, a 20% increase over the annual consumption in the first scenario.

7.5 Implications for the "Riskless" Interest Rate

Our finding of a convenience demand for Treasury debt suggests caution against the common practice of identifying the Treasury interest rate with models' riskless interest rate. We have argued that the observed Treasury rate is $\left(\frac{u'(c_t)}{\beta E_t[u'(c_{t+1})+v'(\theta_t^T;X_t)]} - 1\right)$, with $v'(.)$ positive. It is lower than the "true" riskless interest rate of $\left(\frac{u'(c_t)}{\beta E_t[u'(c_{t+1})]} - 1\right)$ implied by the standard discrete-time C-CAPM model.[24] In order to recover the true riskless rate from the data (the rate that can meaningfully be compared to the riskless rate from a model that ignores the convenience benefits of Treasuries), one has to estimate the convenience yield and adjust Treasury rates by this convenience yield. Our estimated demand curves may be used to measure the convenience yield and make the adjustment.

[24] Duffie and Singleton (1997) make a similar point in the context of the term structure literature, and advocate using swap rates instead of Treasury rates.

Our results also have bearing for puzzles regarding high measured return spreads and excess comovement of spreads. Since many asset market return spreads are measured relative to Treasury interest rates, the demand for Treasury liquidity and variation in this demand will generate high average asset yield spreads over Treasuries as well as comovement in spreads and excess returns across different asset classes. There is empirical support for both of these observations. As noted earlier the magnitude of corporate bond and swap spreads are hard to reconcile based purely on default considerations. The literature also has documented patterns of unexplained comovement. Collin-Dufresne, Goldstein, and Martin (2001) show that credit spread changes within the corporate bond market are highly correlated. Boudoukh, Richardson, Stanton, and Whitelaw (1997) document similar evidence from the mortgage backed securities market. Gabaix, Krishnamurthy, and Vigneron (2006) show that corporate bond spreads and mortgage backed spreads comove. Variation in the Treasury convenience yield is one possible explanation for the comovement phenomena.

8 Robustness

This section present a series of robustness checks of our main regressions.

8.1 Additional Default Controls

Table XI presents results that include other default controls, in addition to the BAA-AAA Moody's spread of earlier regressions. Column (1) presents a default control from Campbell, Hilscher, and Szilagyi (2006) (that is drawn from Chava and Jarrow, 2004). The authors consider a sample of publicly traded firms in the Wall Street Journal Index, the SDC database, SEC filings and the CCH Capital Changes Reporter. If a firm files for bankruptcy, delists, or receives a D rating, over the period January 1963 through December 2003, the firm is labeled as distressed. The percentage of distressed firms in each year is the measure of aggregate default risk. This variable has a correlation of 0.13 with the BAA-AAA spread. Column (2) considers a similar default control which covers a longer time period (1927 - 1997). The default measure is the percentage of firms in the Dun and Bradstreet database that fail in any given year. This default risk measure has a correlation of 0.46 with the BAA-AAA spread. Last, column (3) presents regressions that include the volatility of the stock market to proxy for the risk of default. We measure the standard deviation of the value weighted stock market index (NYSE/AMEX/NASDAQ) over the previous 36 months, ending with June of the present year. The variable has a correlation of 0.78 with the BAA-AAA spread.

The inclusion of alternative default controls does not alter the importance of the Debt/GDP ratio in the regressions. The differences in the coefficient on $log(Debt/GDP)$ in the three specifications is primarily due to the different sample periods for each regression. The results also suggest that the BAA-AAA spread serves as a good control for default risk.

8.2 State Tax Effects

Corporate bonds are taxed at the federal, state and local levels, while Treasury bonds are only taxed at the federal level. Thus, the difference in yields between corporate and Treasury bonds will in part reflect state and local tax rates. Loosely speaking our expression in (2) applies to yields where the two bonds are taxed equivalently. If the measured pre-tax yield on corporate bonds is $\hat{y}_t^C$, then the effect of state and local taxes is to reduce this yield to $y_t^C = \hat{y}_t^C(1 - tax)$, where tax is the tax rate. y_t^C is the after state and local tax yield and is now comparable to the Treasury yield.

The pre-tax yield spread is then given by

$$\hat{y}_t^C - y_t^T = \left(y_t^C - y_t^T\right) + tax\ \hat{y}_t^C.$$

We can think of our previous expression in (2) as applying to the difference between y_t^C and y_t^T. Therefore, we need to introduce an independent variable equal to $tax\ \hat{y}_t^C$ to control for the state and local tax effect.

We construct a time series of estimated state and local tax rates for high-income tax filers for the years 1944-2003 based on data in the IRS publication Statistics of Income. Households who itemize deductions on their 1040 tax forms list taxes paid on Schedule A along with its four components, "state and local income taxes," "real estate taxes," "personal property taxes," and "other taxes." Beginning in 1972, the Statistics of Income lists the state and local income tax component separately. For earlier years, only the total taxes paid deduction is listed.

Furthermore, for each year, the Statistics of Income lists both "adjusted gross income less deficit" and "taxes paid", tabulated by income category. We focus on households in the income category $1,000,000 and higher. This is done for two reasons. First, high-income households are likely more relevant for the pricing of bonds than less wealthy households. Second, for high-income households the vast majority (88.7% on average across the years 1972-2003) of taxes paid are state and local income taxes.[25]

From this data, we estimate a state and local tax rate time series for high-income households going back to 1944. We do this by multiplying taxes paid for each year by 0.887 to measure the state and local income taxes paid by the high income filers. Our estimated tax rate is computed by taking the ratio of this state and local taxes paid to adjusted gross income less deficit.[26]

The results are reported in Table XII. Our results are robust to the state tax controls. In column (2), the coefficient on the tax rate is 0.48 and significant at the 10% level. Theory suggests the coefficient should be one if the high-income households are the only agents who determine the bond yield spread. When we

[25] This is not the case for the full set of households for which the ratio of state and local income taxes paid to total taxes paid averages 53.7% across the years 1972-2003 and is much less stable across years than for high-income filers.

[26] For the years 1951, 1955, 1957, 1959, 1961, 1963, 1965, 1967, 1969, 1971, and 1974 the Statistics of Income does not provide the taxes paid information we need and for 1978 adjusted gross income less deficit is not provided by income category. For these years we linearly interpolate the state and local income tax rate based on the prior and subsequent year of data.

include the BAA-AAA spread (column (3)), the coefficient on the state tax rate turns negative and becomes insignificant. Finally, we note that the average value of the tax rate is 5.2% and the average value of the tax rate variable is 35 *bps*. Even if taxes are a significant determinant of the corporate bond spread, taxes can at most explain only 35 *bps* of the spread.

8.3 Regressions, by Subsample

Table XIII presents results for the main corporate bond spread regression by subsample. The first column reports the results of the regression if we exclude the years 1942 to 1951. During World War II and its immediate aftermath, the government imposed interest rate controls the Treasury market. The Fed-Treasury Accord (Wicker, 1969) effectively fixed the interest rate on short term Treasury borrowings. The evidence in column (1) confirms that our results are not driven by any idiosyncrasies due to this period.

Many Treasury bonds that were issued in the 1910s, 1920s and 1930s were exempt from Federal taxes (Homer, 1977). These tax effects could drive a large wedge between Treasury and corporate bond yields. Column (2) reports results from excluding the years 1925-1941. Column (3) reports results from excluding the years 1925-1951. Again, our main findings are not driven by these periods. The coefficients are significant and of the same order of magnitude as in previously reported regressions.

8.4 Scaling by Wealth

Table XIV presents the results from redoing regressions by scaling the stock of publicly held debt by a wealth measure rather than GDP. In previous regressions we use the GDP scaling to capture growth in the demand for convenience as the economy grows. Alternatively, one may imagine that the demand for Treasuries is a function of financial wealth. Thus we scale by household assets, defined as total household financial assets (including mutual fund assets and pension fund assets), as measured in the Flow of Funds Accounts of the Federal Reserve, Table L.100. The wealth data is available beginning in 1945.

The results from Table XIV are similar to previous regressions for the corporate bond spread. The sign on $log(Debt/FinAss)$ is negative and of the same order of magnitude of previous results. The results for the swap spread and the CP-Bills spread are no longer significant. As noted earlier, our results are weakest when trying to explain the CP-Bills spread.

Finally, we have also redone the group level demand estimates, scaling each group's security holdings by that group's financial assets. The results are not meaningful for some groups whose holdings (of US assets) consists largely of Treasury securities (central banks). We also do not have total asset holdings for the foreign private sector. For the remaining groups, the results are largely consistent with our reported results in Tables VI and VII and are available upon request.

8.5 Excluding Fed Holdings

Table XV presents results from excluding the Federal Reserve Banks' holdings when constructing the stock of Treasury debt measure. In previous regressions, the stock of debt included Federal Reserve Banks' holdings in order to conform to the existing macroeconomics literature. In addition, since Federal Reserve Banks' holdings are not available until 1945, the sample periods are shorter when using the finer measure of publicly held debt. The results are in line with previously reported results with the exception that the coefficients of the swap spread regressions lose significance.

8.6 Level of Interest Rates

Table XVI reports regressions where we include the level of interest rates as an additional covariate. Columns (1) and (2) include a measure of the real Federal Funds rate. The idea is to capture any changes in the stance of monetary policy. The real rate in column (1) is based on the average nominal Federal Funds rate minus the annual CPI inflation rate over the same year. The real rate in column (2) is based on the average nominal Federal Funds rate minus the annual CPI inflation rate over the preceding year.

Column (3) includes the AAA nominal rate as covariate. As noted above, the state tax effect is proportional to the AAA rate. Thus, if one thinks that our tax rate in the tax-effect regression is mismeasured, then only including the AAA rate may be a better control for tax effects. Additionally, Duffee (1988) points out that the Moody's AAA index includes callable corporate bonds, while the Treasury bonds are typically non-callable. Thus the bond yield spread will reflect the option value of calling the bond. Duffee suggests controlling for this effect using the level of interest rates as a regressor.

Uniformly the results in the table show that our results are robust to including the level of interest rates as control. The larger coefficients in the specifications in columns (1) and (2) are because the sample is from 1955 to 2005. As a comparison, only including $log(Debt/GDP)$ as independent variable for the shorter sample yields a coefficient of -1.44 with T-statistic of 7.29.

9 Conclusion

We show that the demand curve for convenience provided by Treasury debt is downward sloping and provide estimates of the elasticity of demand. A hypothetical rise in the Debt/GDP ratio from its current value of 0.38 to a new value of 0.39 will increase the spread between corporate bond yields and Treasury bond yields between 1.5bps (Table I-A, Panel B, column (2)) and 4.25bps (Table IV-B, column (2)).

We also analyze disaggregated data from the Flow of Funds Accounts of the Federal Reserve and find evidence consistent with the aggregate analysis. Individual groups of Treasury holders have downward sloping demand curves. Even groups with the most elastic demand curves have demand curves that are far from flat.

Our results suggest that US government debt is a special asset that offers a convenience yield to investors. Our estimates imply that the value of the liquidity provided by the current level of Treasuries is between 0.21 and 0.54% of GDP per year.

References

[1] Aiyagari, S.R., and Gertler, M., 1991. Asset returns with transactions costs and uninsured individual risk. *Journal of Monetary Economics 27*, 311331.

[2] Bernanke, Ben, 2005, The Global Saving Glut and the U.S. Current Account Deficit, Sandridge Lecture, Virginia Association of Economics, Richmond, Virginia, Federal Reserve Board.

[3] Bansal, Ravi, and John Wilbur Coleman II, 1996, A Monetary Explanation of the Equity Premium, Term Premium, and Risk-free Rate Puzzles, *Journal of Political Economy* 104(6), 11351171.

[4] Barro, Robert J., 1974, Are government bonds net wealth?, *Journal of Political Economy* 82, 1095-1117.

[5] Barro, Robert J., 1987, Government Spending, Interest Rates, Prices, and Budget Deficits in the United Kingdom, 1701-1918, *Journal of Monetary Economics* 20(2), 221-247.

[6] Bohn, Henning, 1998, The Behavior of U.S. Public Debt and Deficits, *Quarterly Journal of Economics* 113(3), 949-963.

[7] Boudoukh, Jacob, Matthew Richardson, Richard Stanton, and Robert Whitelaw, 1997, Pricing mortgage-backed securities in a multifactor interest rate environment: A multivariate density estimation approach, *Review of Financial Studies* 10, 405-446.

[8] Caballero, Ricardo, Emmanuel Farhi, and Pierre-Olivier Gourinchas, 2006, An Equilibrium Model of Global Imbalances and Low Interest Rates, Working Paper, MIT.

[9] Caballero, R.J. and A. Krishnamurthy, 2006, "Flight to Quality and Collective Risk Management, working paper, Northwestern University.

[10] Campbell, John, Jens Hilscher and Jan Szilagyi, 2006. In Search of Distress Risk, Working Ppaer, Harvard University.

[11] Chava, Sudheer and Robert A. Jarrow, 2004, Bankruptcy prediction with industry effects, *Review of Finance* 8, 537569.

[12] Collin-Dufresne, Pierre, and Bruno Solnik, 2001, On the term structure of default premia in the swap and LIBOR markets, *The Journal of Finance* 56(3).

[13] Collin-Dufresne, Pierre, Robert Goldstein, and J. Spencer Martin, 2001, The Determinants of Credit Spread Changes, *The Journal of Finance*, 66, 2177-2207.

[14] Cortes, Fabio, 2003, Understanding and modelling swap spreads, Bank of England Quarterly Bulletin, Winter 2003.

[15] Dittmar, Robert and Kathy Yuan, 2006, Do Sovereign Bonds Benefit Corporate Bonds in Emerging Markets?, working paper, University of Michigan.

[16] Dooley, Michael P., David Folkerts-Landau, and Peter Garber, 2003, An Essay on the Revived Bretton Woods System, NBER Working Paper 9971, National Bureau of Economic Research.

[17] Duffee, Greg, 1998, The relation between Treasury yields and corporate bond yield spreads, *Journal of Finance* 53, 2225-2242.

[18] Duffie, D. and K. J. Singleton (1997). An Econometric Model of the Term Structure of Interest Rate Swap Yields. *Journal of Finance* 52, 1287-1321.

[19] Eisfeldt, Andrea, 2006, Smoothing with liquid and illiquid assets, *Journal of Monetary Economics*, forthcoming.

[20] Elmendorf, Douglas W., and N. Gregory Mankiw, 1999, Government Debt. In John B. Taylor and Michael Woodford (eds.), Handbook of Macroeconomics, Amsterdam: Elsevier Science, Chapter 25.

[21] Elton, E., M. Gruber, D. Agrawal, and C. Mann., 2001, Explaining the Rate Spread on Corporate Bonds, *Journal of Finance* 56, 247-277.

[22] Evans, P., 1987, Do budget deficits raise nominal interest rates? Evidence from six countries, *Journal of Monetary Economics* 20(2), 281-300.

[23] Plosser, Charles, 1987, Fiscal policy and the term structure, *Journal of Monetary Economics* 20(2),343-367.

[24] Gabaix, Xavier, Arvind Krishnamurthy and Olivier Vigneron, 2005, Limits of Arbitrage: Theory and Evidence from the MBS market, forthcoming, *Journal of Finance*.

[25] Grinblatt, M. (2001). An Analytical Solution for Interest Rate Swap Spreads. *International Review of Finance* 2(3), 113-149.

[26] He, H. (2001). Modeling Term Structures of Swap Spreads. Working Paper.

[27] Heaton, John and Deborah Lucas, 1996, Evaluating the Effects of Incomplete Markets on Risk Sharing and Asset Pricing, *Journal of Political Economy 104*, 443-487.

[28] Holmstrom, Bengt and Jean Tirole, "Private and Public Supply of Liquidity," *Journal of Political Economy*, 106(1), 2/98, pp. 1-40.

[29] Homer, S., *A History of Interest Rates, Second Edition*, (New Brunswick: Rutgers University Press, 1977).

[30] Huang, J. and M. Huang, 2001, How Much of the Corporate-Treasury Yield Spread is Due to Credit Risk? Penn State University, Working Paper.

[31] Johannes, M. and S. Sundaresan, 2006, The Impact of Collateralization on Swap Rates, forthcoming, *Journal of Finance*.

[32] Jovanovic, B., and P. Rousseau, 2001, Liquidity effects in the bond market, working paper, Vanderbilt University.

[33] Krishnamurthy, A. (2002). The bond/old-bond spread. *Journal of Finan- cial Economics* 66, 463-506.

[34] Laubach, T., 2005, New Evidence on the Interest Rate Effects of Budget Deficits and Debt, Board of Governors of the Federal Reserve System, Working Paper.

[35] Li, X. (2004). Decomposing the Default Risk and Liquidity Components of Interest Rate Swap Spreads. Working Paper, York University.

[36] Liu, J., F. A. Longstaff, and R. E. Mandell (2004). The Market Price of Credit Risk: An Empirical Analysis of Interest Rate Swap Spreads. forthcoming, *Journal of Business*.

[37] Longstaff, F., 2004 The Flight-To-Liquidity Premium in U.S. Treasury Bond Prices, *Journal of Business*, 77, 511-526.

[38] Longstaff, F., S. Mithal and E. Neis, Corporate Yields Spreads: Default Risk or Liquidity? New Evidence from the Credit-Default Swap Market, forthcoming, *Journal of Finance*.

[39] Reinhart, Vincent and Brian P. Sack, 2000, The Economic Consequences of Disappearing Government Debt, *Brookings Papers on Economic Activity*, 163-220.

[40] Sundaresan, S., and Zhenyu Wang, 2006, Y2K Options and Liquidity Premium in Treasury Bond Markets, working paper, Columbia University.

[41] Vayanos, Dimitri and Jean-Luc Vila, 1999, Equilibrium Interest Rate and Liquidity Premium With Transaction Costs, *Economic Theory 13*, 509-539

[42] Vissing-Jorgensen, Annette, 2002, Limited asset market participation and the elasticity of intertemporal substitution, *Journal of Political Economy*, 110(4), 825-853.

[43] Wicker, Elmus, 1969, World War II Policy of Fixing a Patter of Interest Rates, *Journal of Finance*, 24(3), 447-458.

[44] Woodford, M., “Public Debt as Private Liquidity,” *American Economic Review, Papers and Proceedings 80*, May 1990, pp. 382-88.

Table I-A

Explaining the Corporate Bond Yield Spread

The dependent variable is the corporate bond yield spread, measured as the spread between the Moody's AAA long maturity bond yield and the average yield on long maturity (> 10 years) Treasury bonds, both measure in percentage units. Both data series are from the Federal Reserve. Independent variables are based on the real book value of Treasury debt outstanding, real US GDP, and the spread between Moody's BAA minus Moody's AAA long maturity bond yields, and a control for the slope of the yield curve measured as the spread between the 10 year Treasury yield and the 3 month Treasury yield (*slope*). All regressions include a constant. Panel A presents OLS regressions, with t-statistics based on Newey-West robust standard errors in parentheses. Panel B presents GLS regressions; specifically, Cochrane-Orcutt AR(1) iterated regressions (ρ reported below). Data are annual, beginning in 1925 and ending in 2005.

Panel A: OLS

	(1)	(2)	(3)
$log(Debt/GDP)$	-0.77 (8.09)	-0.70 (7.24)	-0.76 (6.44)
$BAA - AAA$		0.13 (2.91)	0.09 (1.69)
$slope$			0.05 (1.32)
R^2	0.58	0.62	0.61
N	81	81	81

Panel B: GLS

	(1)	(2)	(3)
$log(Debt/GDP)$	-0.63 (4.48)	-0.55 (3.85)	-0.59 (3.93)
$BAA - AAA$		0.19 (3.42)	0.17 (3.21)
$slope$			0.03 (0.91)
R^2	0.17	0.28	0.29
ρ	0.75	0.77	0.77
N	80	80	80

Table I-B

Explaining the CP-Bills Yield Spread

The dependent variable is the annualized yield differential between short-term commercial paper and Treasury Bills, constructed as described in the text. Independent variables are based on the real book value of Treasury debt outstanding, real US GDP, the spread between Moody's BAA minus Moody's AAA long maturity bond yields, and the spread between the 10 year Treasury yield and the 3 month Treasury yield (*slope*). All regressions include a constant. Panel A presents OLS regressions, with t-statistics based on Newey-West robust standard errors in parentheses. Panel B presents GLS regressions; specifically, Cochrane-Orcutt AR(1) iterated regressions (ρ reported below). Data are annual, beginning in 1921 and ending in 2005.

	Panel A: OLS		
	(1)	(2)	(3)
$log(Debt/GDP)$	-0.64 (5.83)	-0.52 (4.30)	-0.24 (2.38)
$BAA - AAA$		0.20 (3.94)	0.38 (7.93)
slope			-0.23 (5.73)
R^2	0.34	0.44	0.63
N	85	85	85

	Panel B: GLS		
	(1)	(2)	(3)
$log(Debt/GDP)$	-0.63 (4.55)	-0.55 (3.87)	-0.28 (2.61)
$BAA - AAA$		0.15 (2.53)	0.33 (7.92)
slope			-0.20 (5.03)
R^2	0.21	0.27	0.52
ρ	0.42	0.37	0.17
N	84	84	84

Table II

Explaining the Swap Spread

The dependent variable is the 10 year interest rate swap spread, measured as the spread between the 10 year swap rate and the 10 year Treasury note yield, both measured in percentage units. Independent variables are based on the real book value of Treasury debt outstanding, real US GDP, and the spread between Moody's BAA minus Moody's AAA long maturity bond yields, and the spread between the 10 year Treasury yield and the 3 month Treasury yield (*slope*). All regressions include a constant. Panel A presents OLS regressions, with t-statistics based on Newey-West robust standard errors in parentheses. Panel B presents GLS regressions; specifically, Cochrane-Orcutt AR(1) iterated regressions (ρ reported below). Data are annual, beginning in 1987 and ending in 2005.

Panel A: OLS

	(1)	(2)	(3)
$log(Debt/GDP)$	-0.89 (1.95)	-0.63 (1.00)	-0.16 (0.34)
$BAA - AAA$		0.32 (0.74)	0.35 (1.19)
slope			- 0.16 (4.14)
R^2	0.21	0.26	0.56
N	19	19	19

Panel B: GLS

	(1)	(2)	(3)
$log(Debt/GDP)$	-1.58 (1.93)	-1.31 (1.95)	-1.06 (1.55)
$BAA - AAA$		-0.21 (0.91)	-0.01 (0.05)
slope			-0.07 (2.16)
R^2	0.32	0.30	0.46
ρ	0.79	0.62	0.66
N	18	18	18

Table III-A

Bond Returns and the Yield Spread

The dependent variable is the percentage excess return on long term corporate bonds over long term government bonds, at one, three, and five year horizons. Return data are from Ibottson, and are annual, beginning in 1926 and ending in 2004. Independent variables are the spread between Moody's AAA long maturity bond yields and the average yield on long maturity (> 10 years) Treasury bonds, and the spread between the 10 year Treasury yield and the 3 month Treasury yield (*slope*). All regressions include a constant. For horizons over one year, the regressions report *t*-statistics based on Newey-West robust standard errors.

	1-year		3-year		5-year	
$AAA - Treasury$	1.79 (2.14)	1.78 (2.12)	4.73 (2.59)	4.66 (2.52)	6.33 (1.99)	6.23 (2.00)
slope		-0.10 (0.40)		-1.07 (1.47)		-2.48 (2.74)
R^2	0.05	0.05				
N	79	79	77	77	75	75

Table III-B

Explaining Bond Returns

The dependent variable is the excess return on long term corporate bonds over long term government bonds, at one, three, and five year horizons. Return data are from Ibottson, and are annual, beginning in 1926 and ending in 2004. Independent variables are based on the real book value of Treasury debt outstanding, real US GDP, and the spread between the 10 year Treasury yield and the 3 month Treasury yield (*slope*). Additional independent variables include the realized returns on long term government bonds over short term bonds (*durationhedge*) and the four factor controls (market, HML, SMB, momentum). All regressions include a constant. For horizons over one year, the regressions report t-statistics based on Newey-West robust standard errors.

	1-year Excess Returns			3-year Excess Returns		
$log(Debt/GDP)$	-0.98 (1.14)	-0.98 (1.05)	-1.01 (1.39)	-4.22 (2.92)	-3.74 (1.99)	-4.91 (2.98)
slope		0.00 (0.01)			-0.66 (0.71)	
durationhedge			-0.19 (4.69)			-0.05 (0.05)
Four-factor Controls	NO	NO	YES	NO	NO	YES
R^2	0.02	0.06	0.31			
N	79	79	79	77	77	77

	5-year Excess Returns		
$log(Debt/GDP)$	-7.90 (2.45)	-6.68 (1.86)	-8.43 (2.91)
slope		-1.68 (1.39)	
durationhedge			-0.05 (1.33)
Four-factor Controls	NO	NO	YES
N	75	75	75

Table IV-A

Explaining the BAA-AAA Spread

The dependent variable is the spread between the Moody's BAA long maturity bond yield and Moody's AAA long maturity bond yield, both measure in percentage units. Both data series are from the Federal Reserve. Independent variables are based on the real book value of Treasury debt outstanding, real US GDP, and two controls for the slope of the yield curve: the spread between average yield on long maturity (>10 years) Treasury bonds and the 10 year Treasury yield (*slopelong*); and, the spread between the 10 year Treasury yield and the 3 month Treasury yield (*slope*). All regressions include a constant. OLS regressions report t-statistics based on Newey-West robust standard errors in parentheses. Data are annual, beginning in 1920 (columns (1) and (3)) or 1925 (columns (2) and (4)) and ending in 2005.

	OLS		**GLS**	
	(1)	(2)	(3)	(4)
$log(Debt/GDP)$	-0.62 (3.44)	-0.86 (4.84)	-0.27 (0.69)	-0.48 (1.59)
slope		0.31 (2.93)		0.17 (3.26)
R^2	0.12	0.33	0.01	0.14
ρ			0.83	0.80
N	87	81	86	80

Table IV-B

Explaining the BAA-Treasury Yield Spread

The dependent variable is the low grade corporate bond yield spread, measured as the spread between the Moody's BAA long maturity bond yield and the average yield on long maturity (> 10 years) Treasury bonds, both measured in percentage units. Both data series are from the Federal Reserve. Independent variables are based on the real book value of Treasury debt outstanding, real US GDP, and the spread between the 10 year Treasury yield and the 3 month Treasury yield (*slope*). All regressions include a constant. OLS regressions report t-statistics based on Newey-West robust standard errors in parentheses. Data are annual, beginning in 1925 and ending in 2005.

	OLS		**GLS**	
	(1)	(2)	(3)	(4)
$log(Debt/GDP)$	-1.31 (5.85)	-1.62 (7.60)	-0.86 (1.99)	-1.26 (4.02)
slope		0.45 (3.73)		0.25 (3.38)
R^2	0.33	0.55	0.05	0.21
ρ			0.80	0.76
N	81	81	80	80

Table V

Who holds Treasury Debt?

This table presents statistics on the fraction of Treasury securities held by various groups. The data are from the Flow of Funds Accounts of the Federal Reserve, and are annual (Q2) from 1945 to 2005. Mutual funds include closed-end fudns and exchange traded funds.

Group	Obs	Mean	Std. Dev.	1945	2005
Federal Reserve Banks	61	.14	.04	.10	.16
Foreign Official Holdings	61	.10	.07	.01	.29
State/Local Governments	61	.09	.04	.02	.10
Banks/Credit Institutions	61	.21	.11	.42	.03
Households and Mutual Funds	61	.27	.05	.26	.16
Foreign Private Sector	61	.04	.05	0	.16
State/Local Government Retirement Funds	61	.03	.02	.01	.03
Private Pensions	61	.03	.02	.01	.02
Insurance Companies	61	.05	.02	.09	.03

Table VI

Semi-elasticity of Demand Curves, by Group

This table presents estimates of the semi-elasticity of the demand curve for Treasury securities, by group. The dependent variable is the corporate bond yield spread, measured as the spread between the Moody's AAA long maturity bond yield and the average yield on long maturity (> 10 years) Treasury bonds, both measured in percentage units. Both data series are from the Federal Reserve. Controls include the spread between Moody's BAA minus Moody's AAA long maturity bond yields, a time trend, and the spread between the 10 year Treasury yield and the 3 month Treasury yield (*slope*). All regressions include a constant. The demand curves are estimated using the total stock of Treasury debt as an instrument. We report the coefficient estimate on $log(Debt/GDP)$ in the first stage as well as the semi-elasticity estimate for each group in the second stage. The Treasury holdings data are from the Flow of Funds Accounts of the Federal Reserve, and are annual (Q2) from 1945 to 2005, except for the Foreign Private Sector for which data begin in 1957. t-statistics based on Newey-West robust standard errors in parentheses.

Group	First Stage Coefficient on $log(Debt/GDP)$	Semi-elasticity	N
Federal Reserve Banks	0.24 (2.14)	-2.72 (1.38)	61
Foreign Official Holdings	0.07 (0.31)	-9.44 (0.31)	61
State/Local Governments	0.58 (3.29)	-1.14 (4.72)	61
Banks/Credit Institutions	0.67 (8.97)	-0.99 (3.41)	61
Households and Mutual Funds	1.12 (11.19)	-0.59 (3.18)	61
Foreign Private Sector	3.03 (4.23)	-0.44 (6.20)	49
State/Local Retirement Funds	1.69 (6.02)	-0.39 (4.79)	61
Private Pensions	1.68 (4.78)	-0.39 (3.91)	61
Insurance Companies	2.37 (20.13)	-0.28 (3.67)	61

Table VII

Semi-elasticity of Demand Curves, by Group

This table presents estimates of the semi-elasticity of the demand curve for Treasury securities, by group. The dependent variable is the corporate bond yield spread, measured as the spread between the Moody's AAA long maturity bond yield and the average yield on long maturity ($>$ 10 years) Treasury bonds. Both data series are from the Federal Reserve. Controls include the spread between Moody's BAA minus Moody's AAA long maturity bond yields, a time trend, and the spread between the 10 year Treasury yield and the 3 month Treasury yield (*slope*). All regressions include a constant. The demand curves are estimated using the total stock of Treasury debt ($log(Debt/GDP)$) and Foreign Official Holdings ($log(\theta^{FOH}/GDP)$) as instruments. First stage estimates are reported in Panel A and second stage estimates are reported in Panel B. The last column in Panel B reports the p-value from the test of the overidentifying restrictions. The Treasury holdings data are from the Flow of Funds Accounts of the Federal Reserve, and are annual (Q2) from 1945 to 2005, except for the Foreign Private Sector for which data begin in 1957. t-statistics based on Newey-West robust standard errors in parentheses.

	Panel A: 1st Stage		Panel B: 2nd Stage	
Group	Coefficient on		Semi-	Overid Test
	$log(Debt/GDP)$	$log(\theta^{FOH}/GDP)$	elasticity	p-value
State/Local Governments	0.60 (3.59)	-0.27 (1.90)	-1.10 (5.06)	0.92
Banks/Credit Institutions	0.67 (8.69)	-0.11 (1.52)	-1.03 (3.54)	0.68
Households and Mutual Funds	1.13 (13.41)	-0.22 (3.24)	-0.61 (3.23)	0.73
Foreign Private Sector	3.04 (6.24)	0.01 (0.02)	-0.44 (6.19)	0.94
State/Local Retirement Funds	1.76 (6.04)	-1.06 (3.64)	-0.34 (4.72)	0.36
Private Pensions	1.65 (4.71)	0.36 (1.30)	-0.34 (3.84)	0.01
Insurance Companies	2.39 (25.52)	-0.26 (3.40)	-0.29 (3.76)	0.33

Table VIII

Change in Demand

This table presents regressions for the sample prior to 1971 and the sample after 1971. The dependent variables are the percentage spread between the Moody's AAA long maturity bond yield and the average yield on long maturity (> 10 years) Treasury bonds; and, the percentage difference between, (1) the return from investing in 6-month commercial paper in January and rolling over in July until the next January, and (2) the return from rolling over Treasury bills over the same period. Control for credit risk is the spread between Moody's BAA minus Moody's AAA long maturity bond yields. All regressions include a constant. t-statistics based on Newey-West robust standard errors in parentheses. Data are annual, beginning in 1925, except for the CP-Bills spread regression where data begin in 1920. Data end in 2005.

	Dependent Variable			
	$AAA - Treas$		$CP - Bills$	
	< 1971	≥ 1971	< 1971	≥ 1971
$log(Debt/GDP)$	-0.52 (6.67)	-1.15 (4.20)	-0.60 (5.91)	-0.75 (1.45)
$BAA - AAA$	0.16 (4.23)	0.13 (1.00)	0.18 (2.48)	0.27 (1.01)
R^2	0.76	0.59	0.60	0.28
N	46	35	50	35

Table IX

Exponential Specification

We estimate the following relation:

$$S_t = b_0 + b_1 e^{b_2 \times (Debt/GDP)} + c\, Y_t + \epsilon_t.$$

where, S_t is the spread between the Moody's AAA long maturity bond yield and the average yield on long maturity (> 10 years) Treasury bonds, both measured in percentage units. Y_t are controls that include the spread between Moody's BAA minus Moody's AAA long maturity bond yields, and the spread between the 10 year Treasury yield and the 3 month Treasury yield (*slope*). The control variables have been demeaned in the regressions. t-statistics based on Newey-West robust standard errors in parentheses. Data are annual, beginning in 1925 and ending in 2005.

	(1)	(2)	(3)
b_0		0.07 (0.42)	0.13 (0.94)
b_1	2.45 (9.50)	2.48 (8.22)	2.66 (6.76)
b_2	-3.03 (9.45)	-3.31 (3.85)	-3.78 (4.38)
$BAA - AAA$			0.07 (1.33)
slope			0.07 (2.02)
R^2	0.91	0.61	0.67
N	81	81	81

Table X

Value of Aggregate Liquidity

This table presents estimates of the value of aggregate liquidity/convenience of Treasury securities. We report how much investors will be willing to pay, as a yearly flow cost (percentage of GDP), in order to enjoy the benefits of a particular level of Treasuries/GDP, starting from a scenario with a Treasury/GDP ratio of zero. We present results for the exponential specification with $b_0 = 0$, $b_1 = 2.5$ and $b_2 = -3.3$.

	Relative Risk Aversion			
Treasuries/GDP	$\gamma = 0$	$\gamma = 1$	$\gamma = 5$	$\gamma = 10$
0.1	0.21	0.19	0.14	0.11
0.2	0.37	0.30	0.21	0.16
0.3	0.48	0.37	0.25	0.19
0.38	0.54	0.41	0.27	0.21
0.5	0.61	0.46	0.29	0.23
1	0.73	0.52	0.33	0.25
3	0.76	0.54	0.34	0.26

Table XI

Alternative Default Controls

This table presents regressions for alternative default controls. The dependent variable is the percentage spread between the Moody's AAA long maturity bond yield and the average yield on long maturity (> 10 years) Treasury bonds. Controls include the spread between Moody's BAA minus Moody's AAA long maturity bond yields and the spread between the 10 year Treasury yield and the 3 month Treasury yield (*slope*). Additional default controls are based on the percentage of companies that fail in a given year ($pctfailed$ and $dnb - pctfailed$, as described in the text), and the annual volatility of the stock market over the preceding three years (*volatility*). All regressions include a constant. t-statistics based on Newey-West robust standard errors in parentheses.

	$pctfailed$ 1963 - 2003		$dnb - pctfailed$ 1927 - 1997		*volatility* 1928 - 2005	
	(1)	(2)	(3)	(4)	(5)	(6)
$log(Debt/GDP)$	-1.43 (5.53)	-1.36 (4.31)	-0.82 (6.52)	-0.94 (6.12)	-0.78 (6.57)	-0.79 (5.65)
$BAA - AAA$		0.17 (1.34)		0.10 (1.89)		0.06 (0.74)
$pctfailed$	0.12 (2.16)	0.07 (1.15)				
$dnb - pctfailed$			-0.09 (0.62)	-0.36 (2.28)		
volatility					3.07 (3.33)	0.87 (0.50)
slope		0.06 (1.16)		0.11 (2.46)		0.04 (1.18)
R^2	0.54	0.64	0.60	0.71	0.60	0.62
N	41	41	71	71	77	77

Table XII

Control for Tax Effects

This table presents results from including a control for state tax effects in our main regressions. The dependent variable is the corporate bond yield spread, measured as the spread between the Moody's AAA long maturity bond yield and the average yield on long maturity (> 10 years) Treasury bonds, both measure in percentage units. Both data series are from the Federal Reserve. Independent variables are based on the real book value of Treasury debt outstanding, real US GDP, and the spread between Moody's BAA minus Moody's AAA long maturity bond yields. The tax rate variable ($taxrate \times AAA$) is computed from the IRS publication Statistics of Income as described in the text. All regressions include a constant. t-statistics based on Newey-West robust standard errors in parentheses. Data are annual, beginning in 1944 and ending in 2003.

	(1)	(2)	(3)
$log(Debt/GDP)$	-0.89 (6.04)	-0.69 (3.30)	-0.69 (3.84)
$taxrate \times AAA$		0.48 (1.76)	-0.16 (0.47)
$BAA - AAA$			0.47 (3.25)
N	60	60	60

Table XIII

Regressions, by Subsample

This table presents regressions for different subsamples. The dependent variable is the percentage spread between the Moody's AAA long maturity bond yield and the average yield on long maturity (> 10 years) Treasury bonds. Controls include the spread between Moody's BAA minus Moody's AAA long maturity bond yields and the spread between the 10 year Treasury yield and the 3 month Treasury yield ($slope$). All regressions include a constant. t-statistics based on Newey-West robust standard errors in parentheses. Data are annual, beginning in 1925 and ending in 2005.

	(1)	(2)	(3)
	Excluding 1942-1951	Excluding 1925-1941	Excluding 1925-1951
$log(Debt/GDP)$	-0.99 (6.34)	-0.72 (4.57)	-1.19 (5.64)
$BAA - AAA$	0.07 (1.36)	0.34 (3.04)	0.24 (2.02)
$slope$	-0.08 (1.96)	0.02 (0.58)	0.05 (1.25)
R^2	0.63	0.65	0.71
N	71	64	54

Table XIV

Scaling by Assets

This table presents result from redoing regressions by scaling the stock of publicly held debt by household financial assets (including mutual fund assets) from the Flow of Funds Accounts instead of US GDP. The dependent variables are the percentage spread between the Moody's AAA long maturity bond yield and the average yield on long maturity (> 10 years) Treasury bonds; the percentage difference between, (1) the return from investing in 6-month commercial paper in January and rolling over in July until the next January, and (2) the return from rolling over Treasury bills over the same period; and, the 10 year interest rate swap spread. Controls include the spread between Moody's BAA minus Moody's AAA long maturity bond yields, and the spread between the 10 year Treasury yield and the 3 month Treasury yield (*slope*). All regressions include a constant. t-statistics based on Newey-West robust standard errors in parentheses. Data are annual, beginning in 1945, except for the swap spread regression where data begin in 1987. Data end in 2005.

	Dependent Variable					
	$AAA - Treas$		$CP - Bills$		$SwapSpread$	
	(1)	(2)	(3)	(4)	(5)	(6)
$log(Debt/FinAss)$	-0.64 (4.64)	-0.64 (4.46)	-0.21 (1.22)	-0.01 (0.06)	-0.37 (1.40)	-0.09 (0.33)
$BAA - AAA$	0.51 (4.92)	0.50 (4.74)	0.33 (2.14)	0.59 (4.57)	0.48 (1.82)	0.79 (3.08)
slope		0.00 (0.11)		-0.25 (5.49)		-0.15 (4.11)
R^2	0.53	0.68	0.17	0.45	0.27	0.56
N	61	61	61	61	19	19

Table XV

Publicly held Debt, excluding Fed Holdings

This table presents result from redoing regressions by excluding Federal Reserve holdings from the definition of the stock of outstanding debt. The Federal Reserve holdings are available from the Flow of Funds Accounts starting in 1945. The dependent variables are the percentage spread between the Moody's AAA long maturity bond yield and the average yield on long maturity (> 10 years) Treasury bonds; the percentage difference between, (1) the return from investing in 6-month commercial paper in January and rolling over in July until the next January, and (2) the return from rolling over Treasury bills over the same period; and, the 10 year interest rate swap spread. Controls include the spread between Moody's BAA minus Moody's AAA long maturity bond yields, and the spread between the 10 year Treasury yield and the 3 month Treasury yield (*slope*). All regressions include a constant. t-statistics based on Newey-West robust standard errors in parentheses. Data are annual, beginning in 1945, except for the swap spread regression where data begin in 1987. Data end in 2005.

	Dependent Variable					
	$AAA - Treas$		$CP - Bills$		$SwapSpread$	
	(1)	(2)	(3)	(4)	(5)	(6)
$log(Debt^{-FED}/GDP)$	-0.61 (4.55)	-0.64 (4.40)	-0.37 (2.56)	-0.14 (0.95)	-0.36 (0.67)	-0.05 (0.13)
$BAA - AAA$	0.42 (3.89)	0.39 (3.62)	0.21 (1.37)	0.50 (4.43)	0.39 (0.92)	0.79 (2.73)
slope		0.03 (0.66)		-0.23 (4.67)		-0.16 (4.11)
R^2	0.69	0.69	0.23	0.47	0.22	0.55
N	61	61	61	61	19	19

Table XVI

Level of Interest Rates

This table presents results from including the level of real or nominal interest rates as control. The dependent variable is the corporate bond yield spread, measured as the spread between the Moody's AAA long maturity bond yield and the average yield on long maturity (> 10 years) Treasury bonds, both measure in percentage units. Both data series are from the Federal Reserve. Independent variables are based on the real book value of Treasury debt outstanding, real US GDP, the spread between Moody's BAA minus Moody's AAA long maturity bond yields, and the spread between the 10 year Treasury yield and the 3 month Treasury yield (*slope*). The real interest rate is computed as the average Federal Funds rate over the year minus either the CPI inflation for the same year (ex-post real) or the inflation for the preceding year (ex-ante real). The nominal interest rates is the Moody's AAA yield. All regressions include a constant. t-statistics based on Newey-West robust standard errors in parentheses. The real interest rate regressions use data from 1955 to 2005. The nominal rate regression used data from 1925 to 2005.

	(1)	(2)	(3)
$log(Debt/GDP)$	-1.32 (4.80)	-1.25 (5.30)	-0.61 (5.43)
$BAA - AAA$	0.19 (0.94)	0.25 (1.76)	0.12 (2.53)
slope	0.06 (1.22)	0.05 (1.11)	0.02 (0.59)
Ex-post Real	0.005 (0.19)		
Ex-ante Real		-0.01 (0.44)	
Nominal AAA			0.04 (3.33)
R^2	0.70	0.70	0.68
N	55	55	81